August 1958

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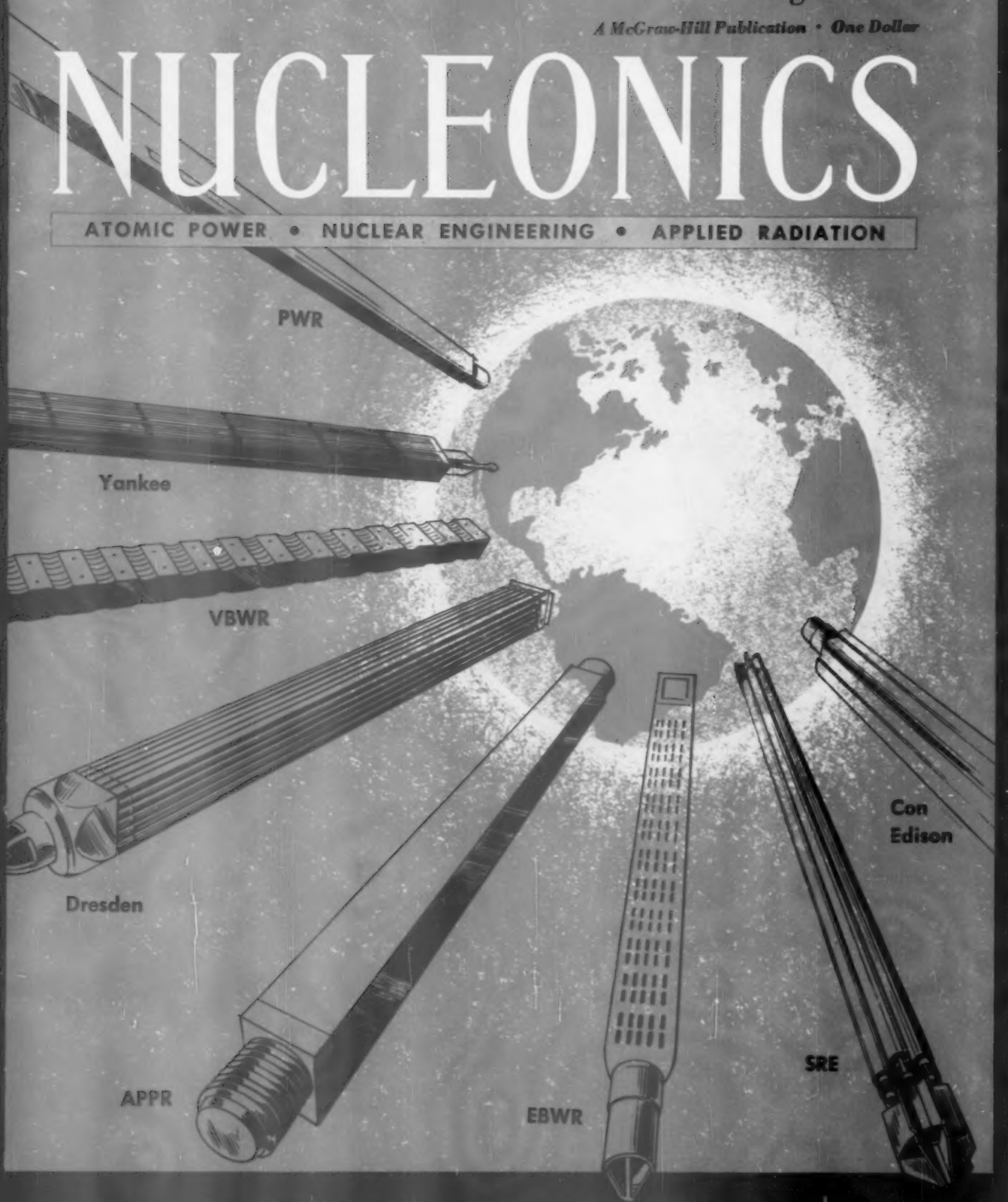
# NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION




## FUEL FOR THE WORLD'S REACTORS

— A Report on U. S. Fuel Technology . . . p. 77

See also Geneva Preview

# Nuclear-Chicago offers complete new nucleonic laboratory instrumentation

More than two years' research went into the 33 *all new* instruments that have been added to the Nuclear-Chicago line now offered to the small or large nucleonic research laboratory. Among these high-quality advance-design instruments are many completely automatic counting systems.

Whether you are just starting a modest radioisotope laboratory or expanding present facilities, call on Nuclear-Chicago. For complete details on the new Nuclear-Chicago line, write for our new Catalog "Q".

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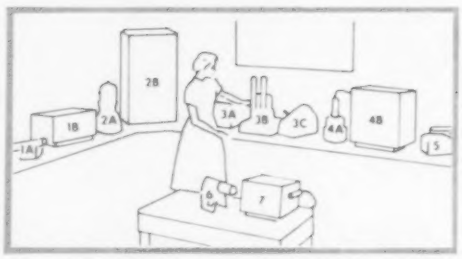


**4A** Model 3054 Manual Sample Changer with Model DS5 Scintillation Detector which features interchangeable alpha, beta, or gamma sensitive crystals connected to Nuclear-Chicago's finest scaler, the **4B** Model 192A Ultrascaler. Model 192A features decade scale of 10,000, one millivolt sensitivity, and precision automatic circuitry.

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**6** Model 2586 "Cutie Pie" features interchangeable ionization chambers for measuring beta, gamma, or x-radiation up to 250 roentgens per hour.

**7** Model 1620A-S Analytical Count Rate Meter offers a wide choice of full scale ranges, four time constants, wide range high voltage supply. It is shown with a Model D34 thin window G-M tube and P11 probe for continuous monitoring or analytical radioactivity determinations.

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# NUCLEONICS

ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION

VOLUME 16 NUMBER 8

AUGUST 1958



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# About NUCLEONICS

## We Go Hollywood

When is a fertile isotope like a Hollywood star? When they're both named Myrnaloy.

But that's getting ahead of our story. Our story goes back more than a decade, to wartime and the days of the Manhattan Project, when everything having to do with the subject of atomic energy was a closely guarded secret. In those days the very word uranium was classified. One of the early devices for getting around mentioning that forbidden word was to use the names of other, commoner elements instead. However that mechanism broke down when *those* elements became of interest to the Project, causing considerable confusion. The final solution was adopted from the British, who had code-named uranium *tuballoy*. (For an interesting sidelight see "When Uranium was 'Tuballoy'" NUCLEONICS, October, 1954, p. 20). Enriched uranium was named "oralloy"; plutonium was called "49," derived from the last digits of its atomic number (94) and its mass number (239).

**HOLLYWOOD STAR 'MIDST NUCLEAR LUMINARIES.** Myrna Loy converses at Brookhaven dinner marking conference on thorium (wartime code name "Myrnaloy") while AEC's Clark Goodman, left, looks on approvingly. NUCLEONICS editor Jerry Luntz is in right foreground; Miss Loy's husband, Howland H. Sargeant, is at her left.

Because thorium was fissionable with fast neutrons, it too received the attention of Manhattan Project researchers. Another code name was required and thorium became "Myrnaloy."

The two Myrna Loys finally got to meet last January. The occasion was an AEC conference on thorium held at Brookhaven National Laboratory. Bernard Manowitz of BNL, who handled the conference arrangements, thought it would be nice to invite the distinguished actress after whom the element they were discussing was named. (She was unaware of her involvement in atomic energy until this moment). She delightedly consented to attend the conference dinner session (see cut). To mark the occasion the laboratory presented Miss Loy with a small sample of thorium in the form of a pendant on a necklace. She acknowledged receipt in an "official" document that reads "Received from Brookhaven National Laboratory—10 grams of Myrnaloy (signed) Myrna Loy."

The thorium conference was productive of more than pleasant moments—significant technical discussion took place, as reported in detail by Manowitz in his part of our special report on U. S. fuel technology (p. 91), a report that we assembled in recognition of the critical importance of that technology to reactor builders here and abroad.

Of particular interest to foreign readers of this special report will be the rundown on fuels and fuel services available from American manufacturers, in addition to official word from the Atomic Energy Commission on fuel export policies.

## Are You Going?

We'll hazard a guess that in recent weeks the question most frequently asked of people in the nuclear business has been "Are you going?". The reference of course is to Geneva, and the Second International Conference on the Peaceful Uses of Atomic Energy. If you asked *us*, the answer would be "Yes—and in force." For three of our editors will be going over, Chief Editor Jerry Luntz, News Editor John Kenton and Associate Editor Hoby Ellis. In addition we will occupy booth 38 among the U. S. commercial exhibits at the Geneva Exposition Hall (see listing of exhibitors on p. 155).

If you're not going we hope that you will let us be your eyes and ears. Our September issue will be devoted exclusively and entirely to a report on the conference. The normal article space will be given over to a full report on the highlights of the technical sessions—from fusion to reactor design to isotope applications. Our Roundup department will contain an on-the-spot report coverage of people, exhibits, and trends, cabled from Geneva.

*—The Editors*

## Coming Features in NUCLEONICS

### Next Month

*Full issue* on Geneva Conference

### Later Months

Improved Reactor-Kinetics Constants

Matrix Method for Scintillation-Spectrum Corrections

Food Irradiation in Britain

Mock Fission Sources

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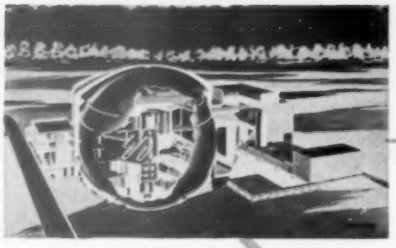
MARINE PROPULSION SYSTEMS

STATIONARY STEAM GENERATING SYSTEMS



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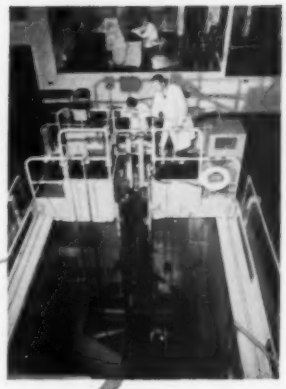
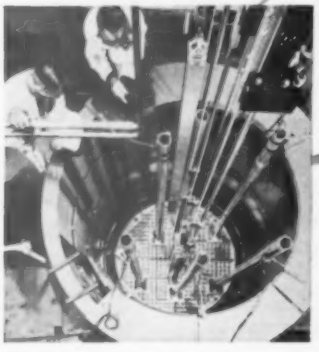
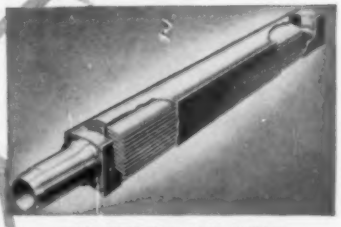
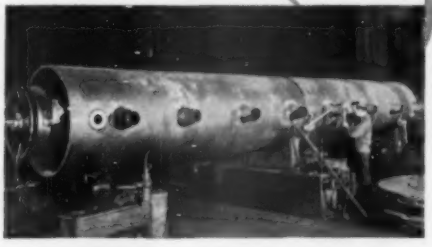


RESEARCH, DESIGN AND DEVELOPMENT





FUEL ELEMENTS AND CORES



HEAVY COMPONENTS

# Some Of The Major Areas In Which B&W Is Contributing To Nuclear Reactor Development

From fuel elements to complete nuclear steam generators, Babcock & Wilcox is actively engaged in all phases of nuclear reactor development.

A skilled staff of scientists and engineers, specialized production facilities, programs of research for nuclear applications, together with long experience in controlling heat and pressure for productive purposes, have combined to establish B&W's position of leadership in putting the atom to useful work.

B&W recognizes that the development of nuclear power challenges industry with unprecedented, complex problems and is contributing to their solution—and to the Free World's progress and strength. The Babcock &Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, New York.

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ATOMIC ENERGY DIVISION

AE-60

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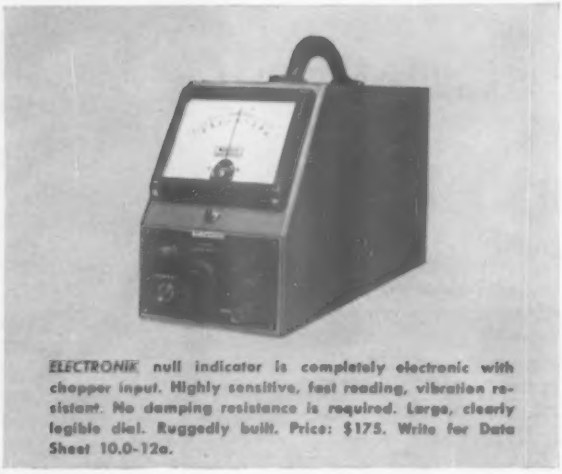

*ELECTRONIK* null indicator is completely electronic with chopper input. Highly sensitive, fast reading, vibration resistant. No damping resistance is required. Large, clearly legible dial. Ruggedly built. Price: $175. Write for Data Sheet 10.0-12a.

## There's a

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*RUBICON* spotlight galvanometer with multiple-reflection optical system and 100-millimeter scale. Simple, sensitive, sturdy, linear. Sharp, parallax-free spotlight index. Insensitive to a-c strays. Price: $95 to $125. Write for Bulletin 320.

Here are three top quality null indicators, each with distinctive advantages for particular applications. Now you can choose the instrument with the exact characteristics you require, without paying for more than you need. Call your nearby Honeywell field engineer for details or write for literature.

MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.

### SPECIFICATIONS

| | MAGNETIK | ELECTRONIK | RUBICON |
|---|---|---|---|
| Voltage sensitivity | 2 microvolts per division | 1 microvolt per division | 1.5 microvolts per division |
| Current sensitivity | .003 microamps per division | .001 microamps per division | .0006 microamps per division (max.) |
| Period | less than ½ second | Less than ½ second | from .6 to 5 seconds, depending on model |
| Input resistance | 600 ohms at max. sensitivity | 1000 ohms at max. sensitivity | 13 to 4000 ohms, depending on model |
| Overload rating | 10 volts, over-range to 45 volts | 1.5 volt | $10^5$ x sensitivity |
| Zero drift | Less than 1 division per hour | Less than 1 division per hour | Negligible |
| Linearity | ±5% of full scale | For null measurements only | ±1% of full scale |

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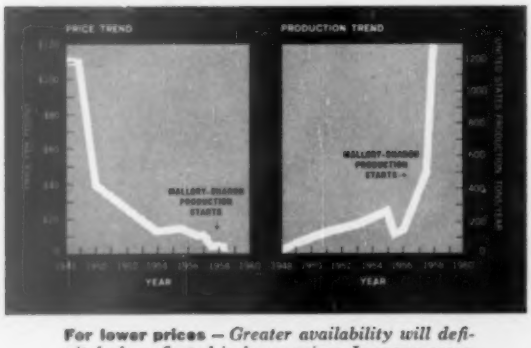
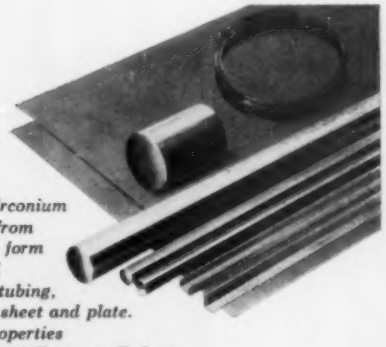
**For availability**—*As Mallory-Sharon's large, modern, sponge plant reaches full production this year, zirconium becomes readily available for all commercial applications.*




**For lower prices**—*Greater availability will definitely be reflected in lower prices. In many cases, the improved performance of zirconium parts much more than offsets their higher material cost.*



**For mill products**—*Zirconium is now available from Mallory-Sharon in the form of rounds, bars and billets, wire, tubing, strip, foil, sheet and plate. Quality and properties are carefully controlled at every stage of production.*

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# ANOTHER MAJOR FIRST IN REACTOR DESIGN...BY AMF

The Engineering Irradiation Facility in the AMF-designed Austrian reactor will give experimenters the first *economical* means of irradiating operating systems at the core face. The first to give a closeup, *horizontal* (as well as vertical) view of the core for direct observation of radiation effects *as they occur.*

This is a light-water, pool-type reactor. It has complete facilities providing for any type of research including materials testing. Each is designed for economical preparation, easy introduction and removal of experiments. Arranged to give maximum capacity for simultaneous experiments are: 6″ and 12″ beam tubes; thru-tubes; pneumatic and hydraulic rabbits; thermal column; bulk irradiation area; gamma radiation facility.

The design is flexible in other ways. While initial operation will be at 5MW, provisions have been made for modifications to much higher power levels in the future.

The Austrian reactor is the *16th* research reactor contract awarded to AMF. These include pool and tank types; light water, heavy water and graphite moderated reactors. *No where else in the world is experience like this available.* The Engineering Irradiation Facility is one example of what it can do.

> *"...after careful evaluation of many proposals, AMF was selected primarily because of special technical features offered in its design and the extensive experience of AMF in building such reactors throughout the world."* Statement of Austrian Study Group for Atomic Energy on awarding AMF its contract.

AT THE GENEVA EXHIBIT—September 1-14 why not discuss your reactor plans with us at Booth 47?

**The Engineering Irradiation Facility is based on an over and under hot cell arrangement. View is through window of flooded bottom cell. The encapsulated experiment—an operative electronic system—is forward from actual experimental position at core face to show interior relationships.**

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**A** Special seamless 11″ OD x 2.937″ min. wall chrome moly vanadium alloy 180° Return for turbine piping use in supercritical (3500 psi at 1100F) power plant service.

**B** Manganese moly alloy Inlet Nozzle for nuclear reactor head on aircraft carrier (A2W) propulsion plant. This nozzle, which is 25¼″ long, is bored throughout to an ID of 13¾″. Outside diameters are 21¼″ and 18¾″.

**C** Stainless clad 16″ OD x 1.093″ wall 53° WeldELL with a 1″ tangent on one end. The stainless lining is ¼″ thick. Designed for aircraft carrier (A2W) nuclear propulsion plant piping, these fittings are made by a unique process developed entirely by Taylor Forge.

**D** Electric Fusion Welded Stainless Steel Pipe in sizes through 22″ OD, made to extremely stringent specifications, and furnished in 20′ lengths for primary coolant piping in the Commonwealth Edison Company's Dresden, Illinois, nuclear power steam generating plant.

**E** This 10″ x 8″ x 8″ Schedule 160 Stainless Steel Wye is typical of special designs produced by Taylor Forge over the years for high pressure-temperature oil refinery service.

**F** There are almost no limitations as to size and wall thickness ratios in which WeldELLS can be produced. This 18″ OD x 3.90″ wall chrome moly fitting is designed for fossil fuel power plant service.

**G** Stainless Steel Welding Laterals of several sizes are used in reactor coolant piping in S5W atomic submarine propulsion plants. This is 14″ x 10″ x 10″ size, with lateral at 50° 30′ angle. Design conditions are 2500 psi at 650F.

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## For Nuclear OR FOSSIL FUEL Power Plant Service

Wherever piping requirements are extremely exacting, where even minute surface flaws cannot be tolerated and interior structure must be perfect—in other words, where the very highest *quality standards* must be maintained, TAYLOR FORGE can be relied upon as a completely dependable source for Welding Fittings, Forged Flanges and Nozzles, Forged Headers and other piping system and pressure vessel components.

The unusual designs and extremely stringent specifications encountered in nuclear power reactor piping provide an excellent example of such exacting requirements. And Taylor Forge has the distinction of having supplied essential parts for important nuclear installations, including nuclear powered steam generating plants and ship propulsion units, ever since the very birth of the "Atom Industry". In addition, Taylor Forge products are installed in every major facility for the production of fissionable materials.

This is quite understandable, of course, because for more than 50 years, Taylor Forge has been a recognized leader in the design and development of power piping and pressure vessel components.

## . . . and for Process Piping

In this field, too, particularly in Petroleum Refining and Petro-Chemical plant operations, severe service conditions often impose most rigorous requirements, so restrictive as to call for greatest care in the selection of designs and materials.

And here, too, experienced engineers and designers have learned to "turn to TAYLOR FORGE" for piping and pressure vessel parts of unquestioned quality. Such products are available from Taylor Forge not only in carbon, alloy and stainless steels, but also in any other forgeable material that may be required.

## . . . for Missile, Aircraft and Machinery Parts

Known everywhere as an outstanding producer of precision forged, rolled and extruded parts for missiles, jet engines and heavy machinery applications, Taylor Forge's eminence is even more emphatically recognized when these parts are required of special materials such as stainless, titanium, the newer so-called "exotic materials," and other metals generally classed as "hard-to-work".

The tremendously large and varied assortment of presses, hammers, ring rolling mills, special machines and related production equipment operated in the five U. S. plants of Taylor Forge (plus one in Canada) . . . the complete laboratory facilities for chemical, physical and metallurgical testing and control . . . the accumulation of superlative technical and engineering skills acquired during more than half a century of experience in this field . . . all these reasons justify the selection of Taylor Forge as the preferred supplier of such products.

NESIUM . . . and all other forgeable metals

**N** Titanium Hemisphere for missile fuel bottle. This closed die hammer forging is 26″ ID with ¾″ thick wall. Also produced in other sizes and metals.

**O** Extruded jet engine component. This part is approximately 60″ long with 24″ diameter head and 4½″ diameter shaft.

**P** Stainless Steel Turbine Shaft for jet engine. Both press forging and extruding operations are employed in forming this part.

**Q** This 42″ OD x 16″ long Stainless Steel Turbine Case is representative of products formed by Taylor Forge ring rolling methods. Seamless rings are made in sizes to 120″ OD with practically any required section.

**R** Heat Sink for long range missile. This press forged Stainless Steel part is 64¾″ OD and 1½″ in wall thickness.

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**Missile and Aircraft Forgings . . .**
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**Electric Fusion Welded Pipe . . .**
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Also supplied for use in nuclear reactor piping is this special wall thickness 16″ OD Stainless Steel Cap.

H

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12″ x 10″ Schedule 160 Stainless Steel Concentric Reducer with square ends. Furnished for classified atomic research facility.

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Taylor Forge is America's first and largest manufacturer of Forged Flanges. This 8″ 2500 lb. Stainless Steel Welding Neck Flange with special spot facing is typical and flanges of this type are made for any pressure-temperature condition.

J

J

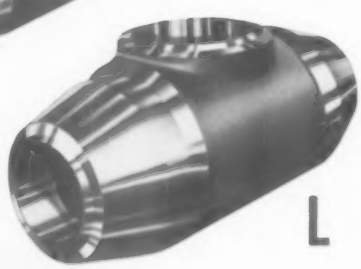
Special heavy wall Stainless Steel Header Type Fitting. Run is 14″ OD and approximately 60″ long with 12″ outlet.

K

K

Bull Head Tees, such as the 8″ x 8″ x 12″ Schedule 160 fitting pictured here, can often improve designs in high pressure-temperature oil refinery and power plant piping.

L



L

Contoured Outlet Headers are made by Taylor Forge in any required size, thickness and outlet arrangement. Widely used for Valve Settings, Gas Compressor Manifolds, Central Power Station Headers, etc., they also find many applications in the process industries.

M

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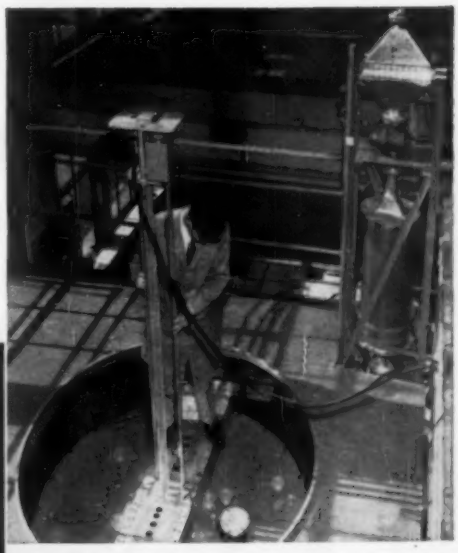

*Above:*

**Subcritical Reactor top view, showing the installation of the vertical ion chamber drive mechanism and the vessel drying system.**

*At left:*

**Subcritical Reactor showing reactor vessel, source flask, horizontal ion chamber drive mechanism, and counting rate recorders.**

On June 19th, 1958, before a distinguished gathering, the Hon. Leslie M. Frost, Premier of Ontario, formally inaugurated at the University of Toronto, Canada's first university-owned subcritical reactor, thus creating an important new facility for nuclear education in Canada.

The Subcritical Reactor, located in the University's Wallberg Building, was designed and built by Canadair's Nuclear Division, and will be used as a laboratory training tool for undergraduate students.

In the reactor, natural uranium rods sheathed in aluminum are mounted vertically in a cadmium-covered aluminum vessel. A heavy water moderator surrounds the rods and an external source of neutrons (yielding $10^8$ neutrons per second), is mounted in a graphite pedestal situated below the vessel. Various fuel lattice spacings are possible through provision of alternative grid plates.

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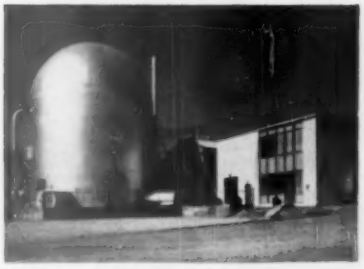

Operating results—VBWR

Experienced personnel—3500 man-years.

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Leadership in the nuclear field is gained from outstanding designs, facilities, and personnel, together with reactor operating experience. Toward this end, General Electric's Atomic Power Equipment Department has designed and built a wide range of power and research reactors, notably the Vallecitos Boiling Water Reactor. It has completed a $20,000,000 integrated nuclear facility, including its headquarter's engineering and manufacturing center at San Jose, California and the Vallecitos Atomic Laboratory, near Pleasanton, California.

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**Fuel**—for power and research reactors, including plate-type and rod-type elements.

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**Development studies**—including advanced reactor design studies in boiling water and other reactor technologies, fuel studies, and physics investigations.

*FOR MORE INFORMATION SEE NEXT THREE PAGES*

GENERAL ELECTRIC

**Vallecitos Boiling Water Reactor** in operation on cool California morning with condenser-circulating-water vapor rising from cooling tower. Inset—Dresden station, largest U. S. all-nuclear plant, nears completion.

## VBWR operation, Dresden design experience, prove potential for

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The VBWR has been supplying the United States' first privately financed atomic-electric power since October 1957, in conjunction with the Pacific Gas and Electric Company.

Operation of the VBWR has shown the direct-cycle boiling water reactor design to have:

- **greater power potential than contemplated**
- **rapid load response**
- **negligible radioactivity carryover allowing direct-contact maintenance on turbine**
- **stability of operation over all pressure and thermal outputs.**

Primary purpose of the VBWR is to obtain operational experience applicable to the Dresden Nuclear Station, the largest all-nuclear plant scheduled in the United States. The Dresden station, rated at 180,000 kw(e) net, will have a G-E dual-cycle boiling water reactor. The station will provide electric power in the Chicago area in 1960.

If its fuel elements were to be redesigned, yet keeping the same core size, this same boiling water reactor plant would have a potential of 245,000 kw(e) net. For a similar system with increased pumping, turbine-generator unit and auxiliary, the potential would be 300,000 kw(e) net.

GENERAL ELECTRIC

**First fuel element for Dresden station,** country's largest all-nuclear power plant, being placed in shipping drum.

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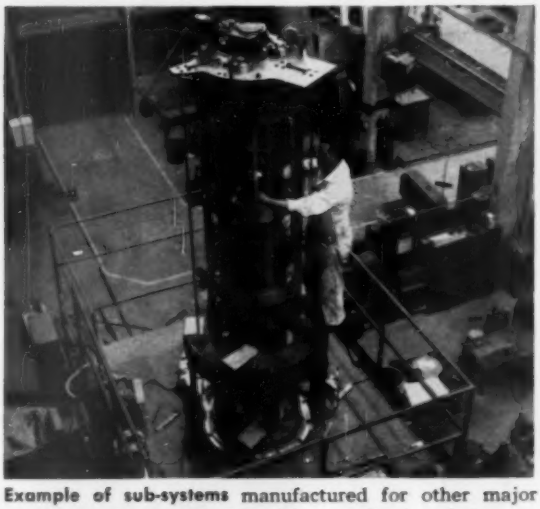
General Electric's commercial atomic facilities are ready to help you with the application and technical advancement of atomic energy. Manned by a top technical staff, the engineering and manufacturing facilities at San Jose, California include general manufacturing, fuel fabrication and special testing areas.

A new mechanized production line reduces costs and provides optimum quality control for rod-type fuel elements. G-E plate-type fuel elements are made with a new pressure-bonding manufacturing process which eliminates need for welding or brazing.

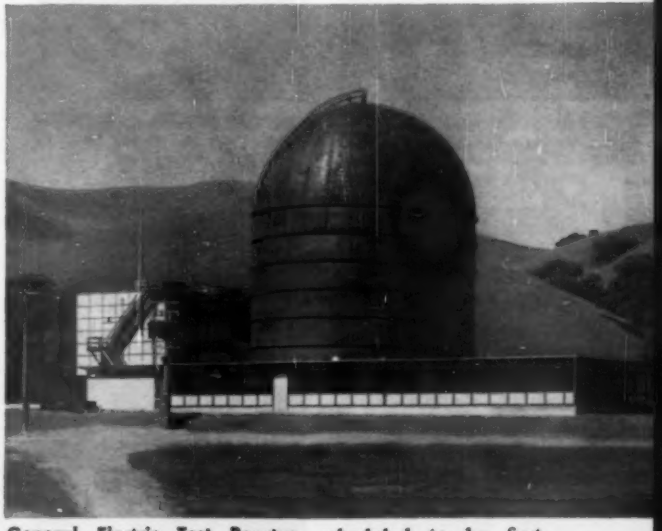
The Vallecitos Atomic Laboratory is a completely equipped commercial facility devoted entirely to nuclear investigation and experiment. Major installations are the Radioactive Material Laboratory, Experimental Physics Laboratory, Vallecitos Boiling Water Reactor, and the General Electric Test Reactor.

Services of the Laboratory include nuclear materials studies, materials irradiation, hot-cell work, physics and radio-chemistry studies, reactor operations research, and irradiation testing in the Vallecitos Boiling Water Reactor and the General Electric Test Reactor.

**Open-pool research reactor** assembled for low-power operating tests before shipment to Spain.



**Example of sub-systems** manufactured for other major reactor projects is fuel-handling mechanism being assembled at San Jose plant.



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*9836-D operating in the linear servo channel of the Penn State Reactor (PSR).*

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Readings are highly accurate because they're stabilized for zero and gain by a combination of a-c amplification and null-balance feedback circuitry. The a-c amplification stabilizes zero; feedback stabilizes gain. Trimmer controls are unnecessary.

For installation flexibility the micro-microammeter is supplied in two models. The 9836-D operates manually from the reactor control panel; 9836-E includes a bi-directional Ledex mechanism actuated from a range selection switch at a remote location.

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# ROUNDUP of Key Developments in Atomic Energy

## British Program Sees Future Pegged to Gas-Cooled; Its Promise Elbows Aside Sodium-Cooled, Fast Breeder

Calder Hall experience, supported by recent theoretical, constructional and experimental programs with higher temperature gas-cooled systems by both the Atomic Energy Authority and the nuclear consortiums, has now led to this system virtually supplanting all others in the British nuclear power effort.

AEA now appears confident it can stretch basically the same system, stay with the same family of engineering technologies and skills, and reach gas temperatures of 700° C (1300° F) commercially by 1970. The specific power, weight and size characteristics of such a plant compare with fast reactor systems and are expected to suit propulsion requirements as well as meet a wide range of power station needs.

Because of this radical shift away from the development concept outlined in the original Government White Paper of 1955 and virtually confirmed in recent statements by top AEA officials, further development of liquid systems has ceased and work on the fast reactor projects and several other systems has been slowed or drastically curtailed.

The original program aimed to have 1,500–2,000 Mw of nuclear power by 1965 and envisaged 12–16 stations. The first and largest group of stations was to have been modestly uprated versions of Calder Hall; liquid-cooled systems were to form a middle group, and fast reactors were to have been phased in at the end.

Events proved that the immediate potential of the system—based on a reactor that had not even been optimized for power production—had been grossly underestimated in the White Paper, even by the British. Also the urgency felt about the fast reactors, based on the need to conserve available uranium supplies by 1965 and on their being the sole means of utilizing the plutonium byproduct, has not persisted. And, against the promise of the higher temperature, gas-cooled graphite reactors, the sodium graphite concept offered no better prospects, but threatened much greater development problems.

Just how conservative were the development rates envisaged was revealed by the 1956 designs for the first round of stations now under construction. The first three stations showed a fourfold increase in output, instead of the two-fold increase expected. Site fabrication of 50% thicker plate had enabled use of larger pressure vessels with double the fuel capacity of Calder; it also permitted a 50% jump in gas pressure, which together with a modest surface temperature rise of up to 25° C and improved finning, doubled the heat loadings from 1.3 Mw/ton to 2.5 Mw. Capital costs dropped to around $400/kw but fuel costs stayed slightly higher than those of existing steam plant.

Within four months of the award of these contracts (NU, Jan. '57, R5), the government lunged into a new massive $2,520-million program which provided for 6,000 Mw by 1965 from 19 stations. All of these were to use natural uranium.

The fourth station at Hinkley Point, awarded eight months later (NU, Oct. '57, 24), achieved a further reduction in capital costs of 20% (to $312) by increasing the output per reactor another 50%. This was achieved largely by better core stacking which increased specific fuel and graphite capacity, by a 20% rise in gas pressure to 175 psi, improved finning on both gas and steam sides, and a higher specific boiler rating. Total output is 500 Mw, and estimated operating cost in 1962 of 7 mills will compare with the best coal-fired stations.

Conversion of Hinkley Point and later civil stations to dual-purpose —announced June 18 by the Ministry of Defense (NU, July '58, 17) —is still somewhat shrouded in mystery. Whether the change augurs an increased need for weapons plutonium, or whether it is a result of the loss of the Windscale reactors to the U. K. program, AEA would not say; but a spokesman

## Congress votes $400-million for atom despite President

AEC's construction authorization program breezed through Congress last month despite a last-minute effort by President Eisenhower to torpedo most of $196-million in new projects added to the program by JCAE (NU, July, '58, 22). The program totals almost $400-million.

Right behind the construction measure, as Congress neared adjournment, was AEC's appropriations bill—$2.4-billion in operating funds and $204-million for construction projects. The bill passed the House late in July and was expected to reach the President's desk early in August. Highlights of budget action:

- First-year funds for a 40-Mw(e) gas-cooled, graphite-moderated reactor were withheld by Congress, pending outcome of an AEC survey this fall to determine private interest in sponsoring the plant (General Dynamics was named by Sen. Clinton P. Anderson (D-N. M.) as an interested firm). AEC is free to go back to Congress early next year if a private sponsor is not found.
- The House Appropriations Committee, for the first time, refused to approve funds for uranium bonus payments and may have thereby killed the bonus program. The group also cut more than $5-million from the program for U purchase.
- $5-million sought by AEC for a radioisotope development program was trimmed to $2-million.
- $3-million for Project Plowshare was approved, giving AEC a go-ahead on its program to explore on a cooperative basis with industry the possibility of using underground nuclear explosions for excavation, mining, power and other commercial applications.

told NUCLEONICS that "minor" technical modifications required in the civil reactors to convert them to dual-purpose were classified, and declined to comment on whether the designed nuclear characteristics, coolant or steam conditions would be affected. One minor modification known to be involved is use of more charge and discharge machines. Bradwell and Berkeley are now at too advanced a stage for modification; only Hinkley Point and the two other 500-Mw(e) stations planned at Trawsfynydd and Dungeness are specifically scheduled for modification, but later stations may also be affected.

The consortia see a practical limit from natural uranium stations of 400–500 Mw output. Stations of this size will be embraced in the 6,000-Mw program for 1965 which was announced in April last year, and might cut the total number of stations to as few as 10.

### High-temperature Program

The new British route to surface temperatures of 1,000° C, and gas temperatures of 700° C, will go via three stages. 1. Natural U with magnox canning will take surface fuel temperatures to 450° C. 2. slightly enriched, sintered U oxide fuel with beryllium cladding, giving surface temperatures of 600° C —possibly going to 700° C using a 100% sintered oxide fuel element. 3. Ceramic mixture of graphite and U oxide together with thorium as a fertile medium in a fissile element clad in an impervious ceramic sheath, giving surface temperatures of 1,000° C.

The first round of stations that will generate the 6,000 Mw scheduled for 1966 will take magnox canning to its limit—possibly 450° C.

The beryllium-ceramic fuel element should be ready for use in commercial stations going into operation after 1965. A large prototype reactor using the elements is expected to be operating by 1961. Use of beryllium will require slight enrichment to about 0.9%, and to combat the poor thermal conductivity of the fuel, the element will consist of clusters of small-diameter rods to increase the surface-to-volume ratio. The actual configuration has not been disclosed, but could possibly be an annular element. Heat loadings should go up three to four times—from 2.5 Mw/ton to the order of 8 Mw/ton and the life from 3,000 to 8,000 Mwd/ton.

Increased fuel and canning costs will be counterbalanced by the increased heat loadings, so that fuel costs remain the same at about 0.16 pence/kwh. Savings will be derived from greatly improved specific characteristics of the boiler and steam plant, due to better steam conditions.

Thermal cycling tests have already been carried out on fabricated elements, and irradiation tests are now proceeding in Harwell's Dido research reactor. Investigations of nuclear characteristics are proceeding in Nero.

Special television viewing cells have recently been completed, which enable micrographs of the heavily-irradiated beryllium elements to be obtained. Capital costs are expected to drop to $244/kw installed and should lead to a 20% drop in power costs to 0.47 pence at 70% power-factor.

As an alternative, a feasibility study is being made on use of heavy water instead of graphite as moderator. The system would be smaller than a graphite system operating at the same temperatures, but economic advantages appear to be marginal, even supposing that heavy water costs no higher than those of the U. S. could be achieved in Britain. Main problem remains that of achieving economically good heat insulation between the fuel element tubes and the pressure tubes in contact with the heavy water.

The high-temperature gas-cooled reactor system, which is considered a longterm development, will depart entirely from metallic fuel components and work on the uranium-thorium breeding cycle. Fuel surface temperatures of 1,000° C will permit gas temperatures of 700° C, comparable with the latest steam conditions and useful for gas turbine applications. The fissile component will be a ceramic mixture of graphite and enriched uranium oxide with thorium as the fertile medium. This ceramic mixture will be enclosed in an impervious ceramic sheath. No details of the core arrangement have been disclosed. Beryllium oxide might later be used instead of graphite as fuel carrier and moderator and sheath.

The nuclear properties of the system are to be investigated in a zero-energy reactor which should be finished this year at Winfrith Heath (NU, Dec. '57, 26). A prototype reactor should be ready in three years, and it is expected that commercial stations should be operating by 1970.

## Informal Accord Reached On Program by AEC, JCAE

AEC and the Joint Committee on Atomic Energy have reached informal agreement on a seven-year, $1.7–1.9-billion civilian power reactor program looking to competitive nuclear power in the U. S. by 1970 and in high-cost areas abroad by 1968.

A 13-page draft of the plan was approved by all AEC commissioners except Chairman John A. McCone (who had not yet taken office) in mid-June, NUCLEONICS learned. A later draft, embodying changes for program flexibility (changes described by JCAE sources as acceptable to AEC) will be published by JCAE shortly; then industry will be asked to comment. Formal adoption as U. S. policy would not come until 1959.

### Fast Reactor Work Slowed

With gas-cooled systems confidently stretched right across the AEA development canvas, fast reactors which threaten to introduce a whole new family of material, fabrication and control problems, now have little priority and certainly will not contribute to the power program in the next 25 years. Original urgency for the fast reactor systems expressed in the 1955 White Paper stemmed from an apparent need at that time to conserve natural uranium. Now, with the certainty of 30,000 tons of uranium available by 1965, the conservation factor vanishes. Furthermore, it was thought they would be the sole consumers of the plutonium by-product from the earlier Calder Hall stations. These stations will now be able to recycle their own plutonium byproducts.

The issue now is whether the Dounreay fast reactor experiment, in face of severe development and maintenance problems, can establish itself as being a better system for burning plutonium than the thermal stations. Dounreay is expected to start operations next year and it will be several years before its potential can be determined.

### . . . and Sodium Dropped

In abandoning further pursuit of liquid-cooled systems after extensive design studies during the last three years, AEA maintains that the sodium system—in spite of its attractive high-temperature, low-pressure characteristics—has too

many serious technological problems, and that the need for enriched fuel makes the pressurized water reactor uneconomic in Europe. Fuel costs alone in the case of the PWR, it is maintained, would work out twice the total cost per unit generated in the 1962 thermal stations. The AEA carried out a detailed design study of the sodium graphite reactor and a research study on the PWR.

While it sees no future for PWR systems for large commercial land or sea power installations, AEA is pushing its development as a propulsion system for submarines. A *Skipjack* unit is to be purchased from the U. S. and fitted into the submarine *Dreadnought* now being built (*see below*), and development of a British-designed prototype at Dounreay is being expedited.

Commenting on AEA work in other areas, J. A. Jukes, economic adviser to the Authority, has said that basic studies have confirmed the low-cost power potential of the homogeneous, aqueous reactor systems and liquid-metal-fueled systems, but these need too much development over long periods, which could not be afforded in view of the much greater urgency of developing the gas-cooled systems. Studies of the organic, liquid-moderated reactors were now solely confined to the single problem of preventing polymerisation of the fluid. Methods of recycling plutonium using inert aluminum carriers, and with uranium and thorium, are currently in hand.

## HMS Dreadnought to Get Westinghouse Reactor

Westinghouse Electric Co., power purveyor extraordinary to the U. S. nuclear fleet, will provide the reactor for Britain's first atomic submarine, HMS *Dreadnought* (NU, April '57, 21).

Amendments to the Atomic Energy Act of 1954 permitting sharing of military atomic information with NATO allies (NU, July '58, 22) permits Britain to purchase a U. S. submarine reactor as a commercial transaction. Rolls-Royce Ltd., acting as agent of the United Kingdom, will buy an S5W (*Skipjack*-type) submarine reactor including core from Westinghouse's commercial atomic power department at Cheswick—not from the Bettis plant—for about $25-million.

According to Admiral Rickover, this will save Britain a minimum of three years and $50–75-million. *Dreadnought*, slated for completion in 1962 or 1963, may now go to sea in 1960. The British will have technical people and naval inspectors in training at Cheswick; their intention is to build the next one themselves, Rickover told the Joint Committee, "but the situation may overtake them and they may find that it is cheaper to buy even a second one from us."

Electric Boat, acting as subcontractor to Westinghouse, will send people to England to help install and test the plant in the hull now already under construction.

Opposition was rising in Congress, however, to the offer of a gift of a submarine reactor to France, made by Secretary of State Dulles to Premier de Gaulle on July 6. Senators Anderson and Pastore of JCAE are among those who are known to feel only Britain should get a U. S. sub reactor now; as Admiral Rickover put it before JCAE, "There are strong Communist elements in some of these countries, and it is easily possible to compromise this information. . . . Be careful as long as we do not know whether the Russians have nuclear-powered submarines that we do not take steps to give this information away too soon."

## Navy Tells Martin Co. To Push Atom Seaplane

Martin Co. has received a $385,000-plus Navy contract to "extend engineering studies on a nuclear seaplane project" the Baltimore firm has been working on since 1953. Designed to advance progress on a nuclear turboprop seaplane, the study contract will cover the entire problem of fitting a reactor into a flying boat's airframe; the Navy specifically said it would consider use of the huge British Saunders-Roe "Princess" plane (NU, July '57, 27; April '58, 26). These engineering studies are to result in completion of a nuclear seaplane in six years.

The contract also covers studies of new airframes designed around current reactor technology, facilities and handling requirements, operations analyses, and new shielding techniques. Martin is now already building for the Navy—and is now testing the third prototype of—the supersonic, longrange P6M Seamaster, which the Navy has called "capable of future atomic flight"; Martin, however, has denied that the Seamaster figures in its nuclear plans.

## G-2 critical at Marcoule; 4 new projects in France

G-2, France's second (and first large) power reactor, went critical July 21 at Marcoule. The dual-purpose unit, begun in November 1955, had a critical mass of 22.5 tons natural U, 0.2 tons more than predicted; it is operating at zero power in air and uncooled. Following physics testing, G-2 will be taken to power at year's end: loaded with 115 tons of natural U (36,000 1-ft slugs in 1,200 horizontal channels in the graphite moderator), G-2's $CO_2$ coolant at 220 psi and 672° F outlet temperature will deliver the reactor's 150 Mw(th) to four heat exchangers feeding steam to a 40-Mw turbogenerator. G-2 is expected to produce 88 lb/yr plutonium and 30–35-Mw(e). It is the world's first power reactor that can be unloaded and reloaded without shutting down. An identical companion, G-3, is to go critical by year's end; together with a smaller predecessor, G-1 (NU, April '56, 22), the three will furnish 220 lb/yr Pu and 50–60-Mw(e) power. In addition to these facilities of France's CEA [AEC], the nationalized utility Electricité de France will complete EDF-1, the first commercial power reactor, next spring (*see p. 21*). And the CEA has just revealed four new reactor projects: Alizé, an enriched-U heavy-water unit for lattice studies at Saclay, and three at a new site—Pégase, for fuel testing; Brenda, to study gas coolants at 1,300° F, and Rapsodie (comprising a 1-Mw(th) and a 10-Mw(th) model), a fast-neutron project using enriched-U–Pu alloy and liquid sodium cooling to study breeding.

## Prospects Brighten for Euratom OK by Congress; Industry, Enthusiastic, Urges Flexibility in Plan

Sen. John Pastore (D-R. I.), international affairs dean of the Joint Committee on Atomic Energy, observed last month that the Eisenhower Administration's Euratom program would do for Western Europe what JCAE Democrats had been attempting since 1956 to do for the U. S.—get some second- and third-generation reactors built with the substantial support of U. S. government money.

For this reason, he took on the task of guiding the Euratom program through Congress before the looming adjournment kills its chances this year. And, for two added reasons—1. the enthusiastic support of the U. S. reactor industry, and 2. the important political implications of a successful Euratom venture—the Administration appeared likely to get Congressional approval this year.

If approval is forthcoming, it will set the stage for the most ambitious atomic program since the atomic and hydrogen bomb projects. The Euratom goal: Six large-scale power reactors operating in West Germany, Italy, France and the Benelux countries by the end of 1962—capacity, 1-million kilowatts.

"The European desire to have six reactors in operation before 1963," Under Secretary of State Douglas Dillon told JCAE on July 22, "means that heavy demands will be made on United States' atomic energy industry to supply specialized reactor components. . . . The joint program should be a major factor accelerating atomic power development."

### JCAE Position

Through several days of hearings during the last two weeks of July, the Euratom proposal encountered surprisingly little in the way of irreconcilable opposition from the Joint Committee. The loudest protest, voiced most often by Sen. Clinton P. Anderson (D-N. M.), was not aimed at the program itself but at the Administration's tardiness in clearing the program for submission to Congress.

"It's pretty late," Anderson complained to Dillon, "to get a matter of this importance, involving several million dollars, and to be told now: 'We (the Administration) took so much time on it you folks will have to hurry up.'"

Because of the late hour, Administration leaders were conceding privately that the entire Euratom "package" would not be approved this year. They were insisting, however, that the program would collapse before it got off the ground unless Congress acted on two-thirds of the package: 1. the bill recognizing Euratom as a sovereign body; and 2. the bill permitting immediate implementation of the Agreement for Cooperation and committing the U. S. to fuel guarantees, capital loans and other arrangements which lie at the heart of the arrangement. Action on the remaining one-third of the package—appropriation of funds for the first year's operations—was seen as delayable until early next year.

**Stall Euratom?**

**As this issue went to press, the Euratom agreement ran into serious trouble. JCAE, unable to get assurances from the Budget Bureau that it would release extra funds voted for the AEC construction program (*see p. 17*), threatened to block Euratom.**

### Industry Reaction

The negotiations preceding submission of the program to Congress were noteworthy in at least two respects: 1. for all but a few loose ends, they lasted less than two months (February–April); and 2. there was no direct participation by industry people from either the U. S. or Euratom. Floberg contended that "it would not have been possible to conduct the negotiations" with industry officials in attendance.

Nevertheless, the reaction of the U. S. reactor industry was generally enthusiastic. Of some 30 replies to a questionnaire sent to the industry by JCAE, none repudiated the arrangement and most lauded it, though quite a few offered suggestions for modifying it or extending some of its concessions to U. S. reactor projects. Sylvania-Corning's comments summed up the industry reaction: "The U. S. negotiators have done an outstanding job under the circumstances." Other comments:

**Allis-Chalmers:** The 1963 target date is "unrealistic and may not be met"; the arrangement should be tightened up to guarantee full dissemination of information developed in the joint research and development program on fuel; consideration should be given to extending the fuel element guaranty provisions to U. S. reactors.

**Atomics International:** Euratom must not be permitted (if the agreement so implies) to make public disclosure of reactor designs, plans and specifications; commended AEC for listing organic-moderated concept as "proven," therefore eligible for the program along with the light-water reactors.

**Babcock and Wilcox:** Program should be restricted to light-water reactors; solution of the third-party liability problem "is of great importance to American industry."

**DuPont:** Time limit might be extended to 1965 to permit consideration of "advanced offspring" of light-water reactors, or of sodium and heavy-water reactors.

**Foster-Wheeler:** Predicted delays stemming from safety requirements, material standards and third-party liability, though none of these will be "serious"; called for flexibility and consideration of heavy-water moderation with various coolants.

**General Electric:** Hailed AEC plans to permit maximum participation by U. S. firms in research-development program; light-water reactors only practical types to permit meeting 1963 date, other types should be reserved for later programs; Euratom should be required to spend all of $135-million loan from Export-Import Bank (or equivalent amount) in U. S.; contracts with U. S. manufacturers must be signed by 1959 to meet schedule and contracts should be conditioned on solution of third-party liability problem.

**General Nuclear Engineering:** Foreign operators might remove fuel charges at first sign of failure to take advantage of guarantees; suggested AEC manufacture fuel elements and guarantee these only, leaving Euratom utilities free to make commercial purchases without AEC guarantees.

**Kaiser Engineers:** Gas-cooled, graphite-moderated, enriched concept may be ready within a year.

**Westinghouse:** Only light-water reactors eligible in view of 1963 date; deadline can be met if program approved and contracts signed by end of this year; "nuclear power and Euratom means too much to Europe to risk having any controversy over hazards in the very first venture. . . . We should stick to proven types like light-water reactors."

## A-Tanker Dead for Year; Other Nuclear Ship News

Hopes of the Maritime Reactors Branch to convert a 22,500-ton T-5 type tanker now under construction to take a nuclear rather than oil-fired propulsion plant were dashed by the Budget Bureau. After disallowing AEC's request for $7.1-million for the tanker reactor, on the ground that the Maritime Administration should file a single request embodying both reactor and hull-conversion funds, Budget turned down Maritime's combined request for $9-million on grounds of economy.

Rep. Melvin Price and Sen. Clinton Anderson declared strong support for the project; Anderson tried in vain to write it back into the authorization bill on the Senate floor. Now, NUCLEONICS learns, MRB considers the T-5 project past, and is going ahead with design of a larger, 60–80,000-ton, tanker. A General Electric design contract on conversion of the T-5 to use a boiling-water reactor (NU, April '58, 25) is being reoriented toward a larger ship.

• States Marine Lines, a world-wide U. S. freight line and owner of Isthmian Lines, was chosen to be general operating agent for N.S. *Savannah;* Matson Line will help handle passenger traffic. Seven bids were made (NU, May '58, 27). Engineering officers, vanguard of the crew, are to report next month.

• The House Appropriations Committee refused $35-million the Navy had asked for advance procurement of long-leadtime components for a second nuclear aircraft carrier; it said this ship type was not yet proven. *Enterprise,* first nuclear carrier, was laid down in February (NU, March '58, 25).

• On the other hand, the House and Senate voted funds for six new Polaris-firing nuclear submarines—four more than the Administration asked. (The Navy wanted six, but the White House cut the request to two.) These are over and above the first three Polaris-armed subs now already under construction as part of the 1958 building program (NU, March '58, 23); they bring to 11 the number of nuclear subs in the 1959 program, which grew from an original request for five—four *Skipjack*-type attack subs, and one *Halibut*-type Regulus-firing sub.

• Bethlehem Steel Co. got a $12.5-million Navy contract to build the land-based prototype for the first nuclear destroyer at West Milton, N. Y.

• De Laval Steam Turbine Co., Trenton, N. J., got into the nuclear submarine propulsion business last month with its first contract—for $4.5-million—for main turbines and other engine-room equipment for the '59 *Halibut*-type. De Laval is building the engines for *Savannah.*

• As part of a $1.5-million waterfront improvement program at Groton to accommodate increasing traffic in increasingly large A-subs, Electric Boat has started a new $287,000, 300-ft service pier for deep-draft nuclear subs. EB is also leasing a 448-ft Navy floating drydock handling craft up to 6,500 tons.

### Nuclear castle

Looking for all the world like a scaled-up replica of a tower of the fabled castle of Chinon 5 mi away, this reactor shield structure for France's EDF-1 has risen in the remarkably short space of 66 days—the time elapsed between taking of this photo and the one in NU, May '58, 19. Occupying cylindrical column at right will be reactor vessel; in square hole, left, will be heat exchangers; entire concrete structure will be enclosed in 140 ft dia. steel sphere

## Blanketless HRE-2 Running 'Remarkably' Well

After 860 hr of continuous operation of Homogeneous Reactor Experiment-2 (680 hr with nuclear heat), Oak Ridge National Labratory director Alvin M. Weinberg says of it, "It has performed remarkably well and we are very pleased with it."

Operating with fuel in both core and blanket regions after a leak breached the two-region zircaloy core vessel (NU, May '58, 26), HRE-2 has been working smoothly in almost every respect, Weinberg says. Eventually, he adds, ORNL will replace the failed core vessel, but only after steadiness and reliability of operation have been proved out over a long period.

Earlier, Weinberg gave some more details on HRE-2's ill-starred week: A first power run in February lasting four days "was terminated when excessive corrosion was noticed for a short period." Then in April the reactor ran "fairly uneventfully" for a week "at increasing power levels culminating in a peak power of about 6-Mw(th) or perhaps 20% higher than rated capacity of 5 Mw. The reactor remained at this power for a short time (about 30 minutes) and the run was terminated when it was found that uranium fuel had transferred from the core into the blanket. Subsequent investigation showed that liquid was exchanging rather freely between core and blanket, but the exact location and cause of failure of the core tank assembly could not be determined."

Corrosion rate of stainless steel in the external piping system was ~2–5 mils/yr, 4–10× higher than loop tests predicted, but may have been "merely the initial high rate always encountered in a loop." (Corrosion rate during the 680 hr of nuclear operation in June was only 0.5 mils/yr). Also, "there was some evidence of uranium phase instability or hydrolysis . . . However, since we have run loops with essentially the same power density without encountering these troubles, we feel [they] ought to be surmountable . . .

"On the positive side of the ledger, the high power runs showed first that an aqueous homogeneous plumbing system can be built which is absolutely tight; the radioactivity was absolutely and completely confined to the high-pressure system . . . Second, we were able to remove 98% of the iodine from the system by means of Ag beds in the vapor space in the low-pressure system. Finally, we were pleasantly surprised at the relative ease with which repairs have been possible even after the system is radioactive."

## Power Shifting Away from AEC on Reactor Plans; Joint Committee, Budget Disputing Leadership

On an otherwise unremarkable day in April, 1957, Rep. Clarence M. Cannon (D-Mo.)—stooped, shrewd, irascible chairman of the House Appropriations Committee and master parliamentarian—arose on the House floor to denounce the Atomic Energy Commission. Accusing AEC of conducting its reactor development program without getting specific approval for federally-aided projects from Congress, he threatened to block all AEC appropriations until the Commission changed its ways.

Last month, Cannon's surprising intervention of 16 months ago had led directly to the point where much of the Commission's control over reactor development had slipped away. AEC's natural role of leadership in atomic power was up for grabs by the Joint Committee on Atomic Energy and the Bureau of the Budget—the former working adroitly to accelerate reactor spending and Budget working desperately to hold the economy line.

A series of events since March of this year has seen the Bureau trim sharply AEC's proposed construction program for fiscal '59; JCAE double the program over White House objections; and the Bureau standing ready again this year, as it did last, to prevent AEC from claiming funds voted by Congress (NU, Jan. '58, 17). During this period, AEC has found itself slapped down hard by the Budget Bureau, has seen the initiative on immediate and long-range acceleration seized forcefully by the Joint Committee, and now finds itself wondering how much of the money voted by Congress for fiscal '59 will be released by the Bureau of the Budget (*see p. 17*).

### Enter Clarence Cannon

At this point, no one must be more surprised by AEC's loss of leadership than Clarence Cannon. In his telling attack of April a year ago, he was out to advance a personal campaign against AEC Chairman Lewis L. Strauss by forcing AEC to bring its appropriations procedures into conformity with those of other agencies handing out federal funds (NU, May '58, 18).

However, special legislation enacted within weeks after his speech (NU, July '57, 19) went far beyond that: it opened the way to JCAE to review AEC's joint government-industry reactor program project by project, to revise the reactor projects it did not approve, and to add those it wanted in the program. By the end of the 1957 Congressional session, AEC had been forced against its wishes to assume complete control over public reactor projects and to schedule design studies on gas-cooled and plutonium-producing reactors as the first step in their construction (NU, Sept. '57, 21). It had the choice of accepting its fiscal '58 construction program as modified by the Joint Committee—or no program at all.

The JCAE success of 1957 (engineered by the Democratic majority) set the stage for a rare seizure of program direction by a Congressional committee. Such direction appears to have been taken on reluctantly by JCAE but, once in hand, has been pursued vigorously. The Democrats had approached the '58 session of Congress (with industry demands for acceleration louder than ever) in a clearly conciliatory fashion. A now-famous letter in this tone, urging bilateral action by JCAE and AEC on long-range goals and a supporting program, went to Chairman Strauss in November from Rep. Carl Durham (D.-N.C.), JCAE chairman (NU, Dec. '57, 18).

What followed can be divided into three phases: 1. JCAE and AEC—after several months of talks—succeeded in restoring harmonious relations, agreed formally on long-range goals, and stipulated that reactor development should be accelerated; 2. most of their work, however, was nullified when the Budget Bureau, taking its strongest position athwart civilian atomic energy in the program's history, pared AEC's construction program from more than $400-million to less than $200-million; 3. Budget's interference was the last straw for JCAE Democrats—they decided to go ahead on their own.

### JCAE Goes to Industry

JCAE's assumption of leadership has been quiet, imaginative and efficient, though not unchallenged. From the first, the move has been marked by a deliberate effort to consult the industry's executives and the reactor experts in both industry and government. This approach has served two important purposes: first, it has given a measure of prestige to what is essentially an invasion of executive-branch domain; and, second, it has anticipated the possibility of criticism on this point and on the question of JCAE's ability to deal with technical considerations.

In fact, such criticism came recently from Alvin M. Weinberg, director of Oak Ridge National Laboratory, who had responded to the JCAE request for an opinion on the gas-cooled reactor:

"It is unclear to me," he offered, "how the Joint Committee can formulate sound technical questions without having a staff somehow comparable to the staff of the Commission itself. The issue I touch upon is the very difficult one of the proper role of Congress in relation to administrative agencies whose jobs are highly technical. My own personal feeling is that the separation of function between Congress and the Commission would be much better understood if the Joint Committee concerned itself primarily with setting forth the goals, and directed its probing toward the progress in achieving these goals, rather than trying to specify the means for achieving the goals."

Ironically, Weinberg was given

**Carl T. Durham**
*Chairman*
*Joint Committee on Atomic Energy*

**Maurice Stans**
*Director*
*Bureau of the Budget*

**Clarence Cannon**
*Chairman*
*House Appropriations Committee*

his opening by the very process JCAE has adopted to preclude such criticism. The Committee's tactic has been to establish a system of small, temporary advisory committees for advice on broad policy questions—such as long-range reactor construction and plutonium production—and to poll entire segments of the industry for advice on specific questions like the gas-cooled reactor project and the terms of the Euratom agreement.

### Advisory Committees

Via the advisory committee system, the Democrats have brought into the atomic energy debate (on their side, in effect) such highly regarded men as Gordon Dean, former AEC chairman; Walter Zinn, former director of Argonne National Laboratory; Henry deWolf Smyth, former AEC member; John A. Wheeler, co-discoverer of U-235; and Chauncey Starr, president of the American Nuclear Society and of Atomics International.

Zinn, Smyth and Starr were members of a five-man panel (the others were Titus LeClair of Commonwealth Edison and James Grahl, American Public Power Assoc.), which helped the Joint Committee prepare its long-range reactor construction program (NU, July '58, 17). Dean and Wheeler served with John Lampe of North Carolina State College and J. Kenneth Mansfield of Combustion Engineering on the panel which found a need for doubling U. S. capability for plutonium production (NU, June '58, 22).

By the same token, the star-studded, long-range reactor construction panel has given JCAE a sharp needle in its campaign to persuade AEC and the Budget Bureau to agree to a comprehensive statement covering long-term U. S. objectives by the end of the current session. Among other things, the Committee is insisting that the paper include a statement of program objectives and general technical objectives; a discussion of the technological program needed to achieve the objectives; estimated costs, organization and administration of the program; a list of privately and publicly owned plants to be built; and a statement of assistance to reactor projects in other countries.

"It is the hope and belief of the Joint Committee," JCAE said in its report on the AEC construction program for fiscal '59, "that the AEC and JCAE can agree on a long-term program statement by the end of the current session of Congress which will serve as a guide for the Executive Branch, the atomic industry and the Congress in planning and executing programs and projects in the next few years. The Joint Committee intends to submit such a report to the Congress."

### Enter Bureau of Budget

Should AEC and JCAE fail to reach agreement this session, a major reason will be the intervention of JCAE's new adversary—the Bureau of the Budget. In its role as the policy arm of the White House for executive agencies, the Bureau not only exercises direct control over every phase of the appropriations cycle (including the rate of spending of appropriated funds) but participates, as well, in major policy decisions of other agencies—particularly those involving the expenditure of large sums of money. The multi-year program envisioned by JCAE fits this description.

In the last year, Budget has pushed itself into the atomic energy picture to an unprecedented extent because, first, of the pressure of the 1957 economy wave and, second, the prospects this year of huge budget deficits over the next two years ($10-billion alone in fiscal '59). Regardless of the Bureau's reasons for interfering, however, two points stand out: 1. the Bureau is not in a position to relinquish its new role in the near future because of the economy pressure; and 2. JCAE does not like it. This was made clear in its report on the authorization bill:

"The Joint Committee is seriously concerned over the dominant role assumed by the Bureau of the Budget in the atomic energy construction program. Again and again, the Committee was advised that the Bureau had disapproved a project, or had withheld funds on a project recommended by the Commission and approved by Congress.

"This the Joint Committee does not approve."

This declaration is at once a protest against the holdback of funds and a tacit admission that little can be done to force Budget to make the authorized allocations.

Thus, though the Joint Committee has come a long way in its fight for acceleration since April 1957, its victory will not be complete until it makes its peace with Budget.

## Strauss 'Decompressing'; Outlines His Plans

In suite 220 of the Executive Office Building, just west of the White House, a man is trying to "decompress" after five demanding years as chairman of AEC and atomic energy adviser to the President. Lewis L. Strauss, who handed both of his "hats" to John C. McCone only a few weeks ago, has found the decompression process "delightful."

Strauss has accepted his new post as special adviser to the President on atoms-for-peace on one condition —he will serve only so long as he "can be of any service" to President Eisenhower. In the immediate future, this means heading the U. S. delegations to the Geneva Conference, in early September, and to the second meeting of the International Atomic Energy Agency in Vienna, later that month.

Then, he hopes to come up with some new ideas on atoms for peace and to promote a dormant project he proposed in the summer of 1956: an international conference of humanists on the peaceful uses of atomic energy. Perhaps, he suggests, the world's philosophers, historians and theologians "can do what the scientists have been unable to do"— develop a formula by which men of different beliefs can live together.

Beyond this, Strauss' major functions "will be to make suggestions and give advice when called on" and "generally to be helpful" to the President.

"What I will do is to try to be of some use in planning and in devising the kind of constructive projects that I have in the past, but which I have been able to do to a less and less degree because of the demands of an exacting administrative responsibility (at AEC) . . . . If I find that is satisfying to me and useful to those with whom I associate, I am in the fortunate position that I am able to afford to continue it.

"If I am not able to be helpful I will go back to my farm." Joint Committee Democrats are convinced that Strauss' function as general helpmeet to the President on atomic energy will give him too much influence over Administration policy.

ROUNDUP

## Pebble-Bed Reactor Study Confirming Early Promise

A feasibility study for AEC on a 125-Mw(e) pebble-bed reactor by Sanderson & Porter (NU, June '57, 19; Oct., 25) was well enough received that AEC ordered continuation of the studies. S & P is starting a fuel-irradiation program at Battelle's pool reactor; an in-pile loop experiment and extensive experimental work are planned. Three different types of balls, made by Sylcor, National Carbon and Minnesota Mining, will be test-irradiated. Meanwhile a number of private- and publicly-owned utilities are said to be interested in the concept, and a new utility group may be formed.

The 125-Mw unit would have a capital cost of $32.2-million, $254/kw, and an operating cost of 7½–8 mills/kwh (5.08 mills for plant cost at 14% fixed charges and 80% load factor, 1.00 mill for operation, and 1.38 minimum to 1.99 maximum fuel cost).

The reactor would be separated into two regions by graphite cylinders, but with no thermal or pressure differential between them; the inner core columns would be filled with 1½-in. dia compacted-powder balls 90% graphite and 10% fuel—thorium and $U^{235}$ in an 11–1 weight ratio (this corresponds to 8% enrichment); the blanket would have 1½-in. dia balls half graphite, half thorium oxide. The initial loading would have $U^{235}$, from then on the plant would run on $U^{233}$ made in the reactor and separated in an on-site fuel-treatment plant. Coolant would be helium at 950 psi, producing steam at 1450 psi, 1,000° F—close to modern steam conditions. All the core and 10% of the blanket would be replaced every 100 days —by dropping balls out the bottom.

The Germans, however, appear to be still nine months ahead in developing this concept (*see p. 26.*)

## Two of 3 Special MTR Cores Are Too Late for Geneva

With an eye on Geneva-'58, AEC planned to run three special cores of particular interest to foreign countries in the Materials Testing Reactor in Idaho. A 20%-enriched U core was run last year (*see p. 114*) and will be reported on in Geneva Paper 1034. Because of fabrication delays at Hanford, the Pu core will only be inserted this month; a $U^{233}$ core follows later this fall.

## Status of World's Power Reactors on Eve of Geneva

| *Reactor* | *Type** | *Mw(e)* | *Status* |
|---|---|---|---|
| **BELGIUM** | | | |
| BR-3 (U. S.-supplied reactor) | PWR | 11½ | Under construction; startup 1959 |
| **BRITAIN** | | | |
| Calder Hall A, (2 reactors) | GCR | 75 | Operating since summer 1956 |
| Calder Hall B, Cumberland (2) | GCR | 75 | Almost completed |
| Chapel Cross A, Dumfriesshire (2) | GCR | 75 | Near completion; startup 1959 |
| Chapel Cross B, Dumfriesshire (2) | GCR | 75 | Nearing completion; startup 1960 |
| Bradwell, Essex (2 reactors) | GCR | 300 | Under construction; startup 1960 |
| Berkeley, Gloucestershire (2 reactors) | GCR | 275 | Under construction; startup 1960 |
| Hunterston, Renfrew (2 reactors) | GCR | 320 | Under construction; startup 1961 |
| Hinkley Point, Somerset (2 reactors) | GCR | 500 | Under construction; startup 1962 |
| Trawsfynydd, Merioneth | GCR | 500 | Site approval being sought |
| Dungeness, Kent | GCR | 500 | Site approval being sought |
| Dounreay, Caithness | FBR | 15 | Near completion, startup June 1959 |
| **CANADA** | | | |
| NPD, Des Joachims, Ont. | PDR | 20 | Work resumed; startup 1961 |
| **FRANCE** | | | |
| G-1, Marcoule | GCR | 15 | Operating since 1/7/56 |
| G-2, Marcoule | GCR | 30 | Operating since 7/21/58 |
| G-3, Marcoule | GCR | 30 | Near completion, startup early 1959 |
| EDF-1, Chinon | GCR | 60 | Under construction, startup 1959 |
| EDF-2, Chinon | GCR | 100 | Just begun; startup 1960–61 |
| EDF-3, Ardennes region | GCR | ? | Site chosen; startup 1963 |
| **GERMANY (WEST)** | | | |
| RWE, Kahl-am-Main (nr Frankfurt) | BWR | 15 | Construction begun; startup 1960 |
| AVR, Jülich (nr Cologne) | PBR | 15 | Construction begun; startup 1960 |
| **GERMANY (EAST)** | | | |
| Nr. Neuglobsow (USSR reactor) | WGR? | 70 | Under construction; startup 1961 |
| **ITALY** | | | |
| AGIP Nucleare, north Italy (U. S.) | † | 150 | Evaluation reactor types underway |
| Edisonvolta, nr Milan (U. S. reactor) | PWR | 134 | Awaits settling financing details |
| SENN, near Anzio | ? | 150 | Studying 9 bids; award due Sept. '58 |
| SIMEA, near Rome (U. K. reactor) | GCR | 200 | Design underway; startup 1962 |
| **NORWAY** | | | |
| Halden | BWR | 20§ | About completed, startup Sept. 1958 |
| **SWEDEN** | | | |
| R-3, Stockholm | PDR | 15¶ | Construction underway; startup 1960 |
| Adam, Västerås | PDR | 75§ | Construction underway; startup 1960 |
| Eve (R-4), south-central Sweden | ‡ | 100 | Design underway, startup 1964 |
| **SWITZERLAND** | | | |
| Polytechnic, Zürich | BWR | 20§ | Design underway |
| Energie Nucléaire, Lausanne | BWR | 5 | Design underway; startup 1964 |
| **U S S R** | | | |
| First experimental plant, Obninsk | WGR | 5 | Operating since 6/27/54 |
| Location unknown | PWR | 420 | Said to be under construction |
| Location unknown | WGR | 100 | Said to be under construction |
| Location unknown | GCDR | 50 | Said to be under construction |
| Location unknown | SGR | 50 | Said to be under construction |
| Location unknown | BWR | 70 | Said to be under construction |
| Location unknown | AHR | 25 | Said to be under construction |
| Location unknown | FBR | 50 | Said to be under construction |
| **UNITED STATES** | | | |
| APPR-1, Ft. Belvoir, Va. | PWR | ~2 | Operating since 4/8/57 |
| VBWR, Vallecitos, Calif. | BWR | 5 | Operating since 8/5/57 |
| Duquesne Light, Shippingport, Pa. | PWR | 66 | Operating since 12/18/57 |
| Con. Edison, Indian Point, N. Y. | PWR | 275 | Under constr.; startup Jan. 1961 |
| Commonwealth Edison, Dresden, Ill. | BWR | 180 | Under construction; startup 1960 |
| Fermi Station, Lagoona Beach, Mich. | FBR | 100 | Under construction; startup 1960 |
| Yankee Atomic Elec., Rowe Mass. | PWR | 134 | Constr. started, startup late 1960 |
| Sheldon Station, Hallam, Neb. | SGR | 75 | Construction started, startup 1962 |
| City of Piqua, Ohio | OMR | 12½ | Design underway, startup July 1961 |
| Rural Coop. Power, Elk River, Minn. | BWR | 22 | Design underway, startup Oct. 1960 |
| Northern States, Sioux Falls, S. D. | BWR | 66 | Design underway, startup 1962 |
| Chugach Electric Coop., Anchorage, Alaska | SDR | 10 | Research-&-devpmt, prelim. design begun |
| Carolinas-Virginia, Parr Shoals, S. C. | PDR | 17 | Res.-&-devpmt. begun, start 1963 |
| P. G. & E., Humboldt Bay, Calif. | BWR | 60 | Design begun; start 1962–63 |
| Penn. Power & Light Co., Pond Eddy, Pa. | AHR | ~75 | Res.-&-devpmt. underway 3 yrs; decision to build due Dec. '59 |
| Florida West Coast group, no site | GCDR | 50 | Awaits AEC approval of bid |
| NRTS, Idaho | GCR | 40 | AEC awaiting industry bids |
| APPR-1a, Ft. Greeley, Alaska | PWR | ~2 | Under construction |
| ALPR, NRTS, Idaho | PWR | 0.2 | Near completion |

*—REACTOR TYPE ABBREVIATIONS: AHR—Aqueous Homogeneous; BWR—Boiling water; FBR—Fast breeder; GCR—Gas cooled; GCDR—Gas-cooled deuterium-moderated; OMR—Organic moderated; PBR—Pebble-bed; PDR—Pressurized deuterium; PWR—Pressurized water; SDR—Sodium-deuterium; SGR—Sodium-graphite; WGR—Water-cooled, graphite-moderated

† Vitro has consultation-&-design contract; AGIP Nucleare considering a U. S. PWR, BWR or OMR

‡ Deuterium-moderated; liquid and gas cooling both still under consideration

§ Mw(th) in case of these process-steam or space-heating reactors

¶ 15 Mw(e) plus 75 Mw(th) heat

# Reactor News

## NUCLEAR-EXPLOSION MOTOR FOR SPACE?

A new concept of propulsion employing controlled nuclear explosions, for space applications, is the subject of a one-year, $1-million feasibility study being undertaken by General Atomic division of General Dynamics for the Air Research and Development Command. The new concept, using a series of controlled detonations within the atmosphere and beyond, compares to previous concepts of nuclear space-ship propulsion (NU, March '58, 21) as the internal-combustion gasoline engine compares to a boiler-fed steam turbine. Continuation of the program will be based on results of the study during 1959.

## DISCLOSURES ON A-ROCKET ADVANCES

Three approaches to SNAP (satellite nuclear auxiliary power: NU, March '58, 20) are being pushed, AEC's rocket chief, Col. Jack L. Armstrong, told JCAE back in January in testimony just released. SNAP-1 uses cerium-144 as heat source; Martin Co. is prime contractor, and Thompson Products is developing the rotating machinery. "We will get [deleted] electrical energy out of these two wires for 60 days," Armstrong said. SNAP-2 is a thermal reactor being developed by Atomics International and expected to be operational in five years. SNAP-3, based on a Russian idea and being pushed at Westinghouse, is a thermocouple using a mixed valence oxide: one end is cooled, the other end heated, and electricity flows out; instead of the usual 1% efficiency of thermocouples, this is 8% efficient and gives promise of going as high as 25%. "If this pans out," said Armstrong, "we would then use polonium as a radioisotope for a heat source on one side, and then we would have a very close approximation of direct conversion of atomic energy into electrical energy." Also disclosed: Project Snooper, an AI project for an ion engine using cesium ions as propulsion source, for an unmanned vehicle starting from a satellite orbit.

## AI'S REACTOR FUSE WORKS

A successful test of the reactor safety fuse which Atomics International has been developing for AEC (NU, June '57, 116) was made last month at SPERT-1. The fuse, a model for swimming-pool reactors, prevented excess power rise during a severe transient while the reactor was on a 0.01-sec period: it terminated the surge at a level 25× lower than the reactor would have reached with no fuse, and permitted generation of less than 1/10 as much energy. Vital part of the fuse is a cylinder the top part of which, outside the core, contains boron trifluoride gas which is automatically released, in case of transient, into the lower part of the cylinder within the core, quenching the transient. Another AI fuse was successfully tested earlier at Hanford.

## AUSTRIA GETS SECOND REACTOR, A TRIGA

Austria, which ordered its first reactor, an AMF pool, only two months ago, is ready to order a second: a General Atomic Triga (*see p. 116*) for the Vienna Polytechnic. In order to accommodate vertical beam tubes, the Vienna Triga's pool will not be sunk below ground as contemplated in the original GA design but will be housed in a tower.

## AMF'S SIXTEENTH SALE TO IRAN

AMF Atomics has sold another 1-Mw pool reactor, its 16th research reactor sale, to the University of Teheran for its new science center in Amirabad, a suburb of the Iranian capital.

## PWR ON FOUR LOOPS

The Shippingport PWR, designed to operate at full power of 60 Mw on three loops with the fourth held as a spare, has been run since May with all four loops delivering steam, but at lower unit power to make a total output of 60 Mw.

## PUERTO RICAN CENTER STARTED

Ground was broken July 28 for AEC's Puerto Rican Nuclear Center at Mayagüez (NU, Nov. '57, 26).

## REACTOR COMPLETIONS

The MIT research reactor, a heavy-water type, went critical July 22. . . . A 50-kw(th) Atomics International solution-type research reactor went critical on July 28 at the Institute for Nuclear Research in West Berlin; $30,000 worth of uranyl sulfate (1,800 gm of $U^{235}$ contained at 19.9% enrichment) prepared by Mallinckrodt were flown to Berlin (*see p. 82*), first time a foreign shipment was made in solution form (rather than as solid salts). Another load of plate-type elements was flown to Hamburg for the Babcock & Wilcox-built pool reactor nearing completion there. Two other AI reactors crated and shipped from Los Angeles were another 50-kw solution type for Enrico Fermi Nuclear Study Center in Milan, and a smaller L-77 model solution type for the Geneva conference exhibit.

## NBS SEEKING RESEARCH REACTOR

National Bureau of Standards has initiated plans for a long-desired research reactor. Carl O. Muehlhause and H. H. Landon have joined NBS as nucleus of a group to determine the needs, and eventually to plan the facility.

## STUDY BYPRODUCT RADIATION AT HALLAM

Atomics International has received a $76,000 study contract from AEC on feasibility of using sodium coolant in the Hallam, Neb., power reactor as a high-level radiation source for industrial processing. Consumers Public Power District of Nebraska, on whose grid AI will build the reactor, has long (NU, Jan. '56, 14) been intrigued by the economic promise of using sodium for double duty: as reactor coolant and as a byproduct radiation source for food preservation, plastics processing, drug sterilization, etc. AI's study will include design of a radiation processing plant to adjoin the power station.

## FERMI COMPONENTS PROGRESSING

Byron Jackson division of Borg-Warner Corp. has delivered to Lagoona Beach, Mich., the tank for a 34-ft high, 6 ft dia, 11,800 gpm liquid sodium pump—world's largest—for the Enrico Fermi fast breeder reactor. The mammoth primary coolant pump will force sodium at 1,000° F through the reactor core and blanket . . . Meanwhile at San Jose, Calif., General Electric has completed the fuel-handling manipulator, also 34-ft high, that will be able to select, withdraw and replace any of 600 fuel elements remotely by means of electronically-controlled accurate positioning mechanisms.

## 3 FIRMS GET SODIUM COMPONENT WORK

Griscom-Russell Co., Alco Products and Combustion Engineering, picked from 15 bidders, have received AEC contracts for preliminary design and analysis of heat exchangers and steam generators for use with liquid sodium coolant—part of AEC's effort to develop less expensive and more reliable non-nuclear sodium-system components that can operate at high temperature and pressure. Other component contracts will follow.

ROUNDUP

# World News

### Germans Start Power Reactor: Neon-cooled Pebble-Bed

Construction is about to start in West Germany on a $9.5-million, 15-Mw(e) pilot plant by a team of Friedrich Krupp of Essen and Brown Boveri & Co. of Mannheim (NU, June '57, 23). Because of the delays attendant on RWE's purchase of a U. S. reactor (NU, July '58, 26), this first all-German-designed power reactor is also the first power project to get underway. The new design is a high-temperature (1,000° C) pebble-bed unit with ceramic fuel elements of uranium and thorium carbide, graphite moderator, and neon cooling. It will have an operating cost about the same as that of a conventional plant, and construction costs only slightly higher; fuel costs will be lower, as a fuel life of 10–15 years is claimed. Ordering the plant is an association of 10 public power supply firms in the Ruhr and the north (titled Arbeitsgemeinschaft Deutscher Energieversorgungsunternehmen zur Vorbereitung der Errichtung eines Leistungs-Versuchsreaktors, it is happily known as AVR). The reactor will be built in Jülich, 25 mi west of Cologne, at the atomic research center of the state of North Rhine–Westphalia (NU, Jan. '58, 25); it is to start in 1961. Degussa, Siemens-Plania, and other German firms worked with Krupp and Brown Boveri in developing the design. If results are favorable, AVR will order a 100-Mw(e) reactor based on the pilot plant.

### Japan Plans Atomic Training Ship

Japan's Atomic Industrial Forum has proposed construction of a 3,000-ton, $8-million nuclear-propelled training ship with a 6-Mw(th) reactor to be built by 1962 or 1963. Ten major shipping and shipbuilding groups joined in the decision to build such a "small but useful" craft, ending 2½ years of maneuvering. Asserting this did not mean the Japanese don't know "what size A-ships will be most economical and what kind of reactor to mount" on them, a spokesman explained that "since Japan can't afford to waste money, we're timing our shipbuilding so that we'll be better informed when time for installation of the reactor comes: the *Savannah* will be operating by then." Westinghouse and General Electric are expected to bid.

### Melusine, French Pool, Goes Critical

The 1.2-Mw(th) pool reactor Melusine went critical July 1 at France's Grenoble nuclear research center less than a year after construction started. Only imported components were the U. S.-made enriched-uranium fuel elements.

### Both Windscale Reactors Doomed

Windscale No. 2, innocent bystander when Windscale No. 1 suffered a disastrous fire but shut down ever since as a precautionary measure (NU, Nov. '57, 26), will probably never be started up, the British Atomic Energy Authority predicted. Sir William Penney of AEA said it would take 2–4 months to evaluate the recommendations of a special technical committee for reactivating the undamaged unit which, with its sister reactor, has long been Britain's only source of plutonium. The recommended procedures (chiefly new instrumentation) would cost at least $1.4-million, he said; the reactor, designed for 10-year life, has served seven.

### Swiss Reactor Co. to be Nationalized

Unable to keep up with mounting costs, Switzerland's joint nuclear power research firm, Reaktor A. G. (NU, June '56, 19B), has thrown in the towel. The government-backed firm founded by 125 private companies has voted to turn its Würenlingen research center over to a national foundation, to be operated by the Zürich Polytechnic Institute, Europe's greatest technical university.

### IAEA Board Proposes Larger Budget

A $5,225,000 administrative budget for 1959, $1,760,000 greater than that for 1958, is to be proposed by the 23-nation Board of Governors of the International Atomic Energy Agency to IAEA's second General Conference which meets Sept. 22 in Vienna. The Board also recommends increasing from $250,000 to $1.5-million the "general fund" from which most of the Agency's operational programs will be financed . . . IAEA recently received two mobile isotope labs from the U. S.

### B&Ws of the World Unite

Babcock & Wilcox Ltd., Britain's largest manufacturer of steam plants for nuclear power stations, is to pool its technical knowledge and practical experience with that of Babcock & Wilcox Co. of the U. S. Although the British firm originated from the American one, there has been no financial link between the two since 1891 when the English company became a separate organization.

### Canada Starting First Thorium Plant

Canadian production of thorium salts will begin next January if newly-formed Rio Tinto Dow Ltd. gets a projected $1-million plant at Blind River, Ont., built on schedule. The new firm was formed by Rio Tinto Mining Co. and Dow Chemical of Canada to produce thorium and rare earths from uranium mining byproducts in the Blind River–Algoma area. Initial production of the plant will be 100–200 tons/yr of crude thorium concentrates, refined metallurgical-grade thorium sulfate and thorium oxide.

### Uranium News the World Around

Degussa of West Germany has obtained exclusive evaluation rights from Spain's AEC on a Spanish patent on a new U-refining method . . . Southwest England—Cornwall, Devonshire and Somerset—are being prospected for uranium; air surveys have resulted in some exploratory drilling, and abandoned mines are being reopened . . . Shinkolobwe, world's richest U-mine in Belgian Congo, has already yielded 373,205 tons of U-ore, bearing 9–10-lb/U per ton of ore . . . Soviet geologists are reported to have made several rich strikes in Bulgaria, 45 mi from Sofia. They have cordoned off the whole area . . . Danish researchers are studying Greenland ores to determine if they warrant building a full-scale U-ore processing plant there . . . Japan's Atomic Fuel Corp. will import 1,250 lb of semi-refined natural uranium—"yellow cake"—from Canada for refining at the pilot plant at Tokai-mura . . . Spain's Cortes has passed a law permitting private mining companies to prospect for and mine radioactive minerals.

### Austria Finishes Heavy Water Plant

The Austrian Nitrogen Works Co. of Linz has completed a pilot plant for heavy water production, and plans an industrial-size one, as part of its effort to enter the nuclear materials field.

# News in Brief

### Martin Reorganizes, Rauth New Head

Martin Co. has quietly reorganized its nuclear division, creating five departments under a new division head: J. Donald Rauth, formerly procurement director. He succeeds Tibor F. Nagey, new director of research at Allison division of General Motors. New department heads under Rauth are John C. Robinson, reactor components; Jerome Morse, isotopes; Fred C. Hittman, reactor systems; Jack Hunter, engineering; C. C. Christensen, nuclear sales. The reactor systems group will concentrate its efforts on development of stationary power reactors in the 100 Mw(th) range, on portable power reactors and on heat reactors. Nuclear components, under Robinson, will produce fuel elements, reactor controls and control rods. A new department—propulsion—will be activated as soon as a program can be established and a capable man can be found to run it; Martin is already in the nuclear aircraft program but plans to enter other nuclear propulsion fields, including rockets.

### AI, Aerojet Expand

Atomics International's $2-million remote handling facility, to be completed May 15, 1959, was begun by Bechtel Corp. Part of a building program at AI's Santa Susana, Calif., field labs (NU, June '58, 27), it will include four hot cells for research on sodium and organic reactors . . . Aerojet-General Nucleonics has designed a 24,000-sq ft engineering office and an 18,000-sq ft lab and shop for its San Ramon, Calif., facilities for expanded reactor production. Occupancy is expected this fall, when AGN will expand from 250 to 400 employees.

### General Atomic Moves In

At last, 250 staff, equipment and head offices of General Atomic moved from temporary quarters in the old Barnard school in San Diego into their new $10-million quarters: the John Jay Hopkins Laboratory for Pure and Applied Science on Torrey Pines Mesa in northern San Diego (*see photo*). Design of the facility embodies the

concept of interplay of many scientific disciplines for easy contact and exchange of ideas, thus, the central building will contain the library and cafeteria. The two surrounding arcs contain 80 labs. At rear, the experimental building; at right, a two-story administration-engineering building. In the 240,000 sq ft of the entire complex are a critical assembly, a TRIGA reactor, controlled fusion experimental apparatus and a linear accelerator. The last unit will be completed this month.

### Fluor Gets AEC Nod on Waste System

AEC has authorized Fluor Corp. to proceed with a $300,000 waste calcination system at the National Reactor Testing Station. The work will be done under a modified contract originally covering only a feasibility study. Calcination of fission products will permit storage in dry underground vaults, saving space and easing handling.

### Nebraska Dedicates Atomic Station

At ground-breaking ceremonies one mi north of Hallam, Neb., Consumers Public Power District dedicated its newest plant as the Sheldon Station in honor of C. C. Sheldon, treasurer and member of its first board of directors. The plant will go into operation in 1961 as a 100-Mw(e) conventional steam plant; alongside the boiler (and feeding a common turbine: NU, Feb. '57, R2) will be built a 75-Mw(e) Atomics International sodium-graphite reactor, to be completed in 1962.

### News from State Houses

Gov. Albert Rosellini of Washington has set up a coordinator-council type of organization like that of Ohio (NU, March '58, 24) to regulate state atomic activities. Coordinator is Gordon Cochrane, of Hanford's technical staff; councillors are Paul J. Raver, Seattle City Light Co., chairman; Edward Wells, Boeing; Milo Harris, State Medical Ass'n.; W. E. Johnson, Hanford general manager; and H. de Wayne Kreager, State Dept. of Commerce . . . Gov. Robert Meyner of New Jersey has signed legislation creating a five-man commission to regulate radiation sources, working with state health and labor units . . . The Atomic Industrial Forum has published a 44-page survey of state activities in the atomic field.

### Reactor Grade Zirconium Offered for Export

Hafnium-free zirconium oxide and tetrachloride are available in tonnage quantities for export to free-world nations, Columbia-National Corp. announced. With no substantial production of Hf-free Zr sponge known outside the U. S., this for the first time makes possible production of reactor-grade Zr sponge and mill products by foreign firms with Kroll-process facilities.

### Study Sees Economic Power by 1980

That elusive goal, economic nuclear power, will be reached before 1980, the latest of the National Planning Ass'n.'s atomic surveys shows. In 1980: 20% of all electric power generation, and ¾ of power plants built, will be nuclear; power cost will be 6 mills, and the nuclear industry will have a $10-billion capital investment.

### Bill Would Aid Universities with Reactors

JCAE has held hearings on Sen. Clinton Anderson and Rep. Melvin Price's bills to facilitate indemnity coverage for universities having research reactors, by exempting them from the obligation to carry private liability insurance as a prerequisite to qualify for federal indemnity under last year's Price-Anderson law.

### Phillips Opens Big U-Mill

Operations have begun at Phillips Petroleum's 1,725 tons/day ore-processing mill 25 mi north of Grants, N. M., in the Ambrosia Lake area. The mill's output will be sold to AEC under a contract running through 1966.

### NACA Gets Construction Permit

AEC has issued a construction permit to the National Advisory Committee for Aeronautics for its planned 60-Mw(th) materials testing reactor to be built near Sandusky, Ohio, a site AEC's safeguards committee had criticized (NU, Jan. '58, 20). The $10.8-million facility for nuclear plane research is to be ready by late 1959.

## ROUNDUP

### Nuclear Icebreaker Bill Progresses in Congress

The Senate received a favorable committee report on the House-passed bill for a U. S. nuclear icebreaker, is expected to give it final approval this month. Planning for the ship is already underway; its size will depend on its mission—how many helicopters it should carry, how much scientific equipment, whether it will operate in the Arctic or Antarctic.

### Protestant Church Weighs Reactor Gift to Japan

The Protestant Episcopal Church's joint commission on peaceful uses of atomic energy is recommending that the church give a $400,000 research reactor to St. Paul's University, Tokyo, "in the name of the whole church." The reactor would also make radioisotopes for clinical use at St. Luke's Hospital in Tokyo. Both university and hospital are maintained by a Japanese branch of the Anglican Communion.

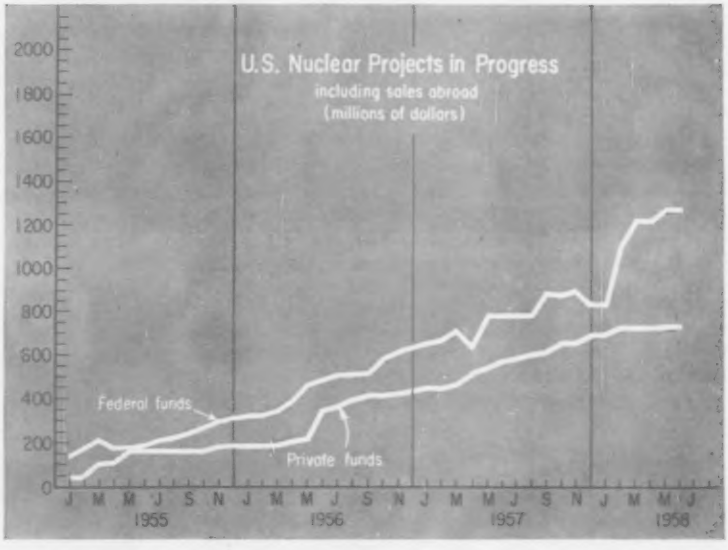
### Top Officials Resign At Metals & Controls

Both Rathbun Willard, board chairman of Metals & Controls Corp., and Carroll Wilson, president, have given up their positions. Rathbun, 76, a founder of the firm in 1916, retires; Wilson, AEC's first general manager and president of M & C since 1956, resigned and was named chairman of an advisory committee. George L. Williams, treasurer of the firm, becomes acting president of both M & C and its subsidiary M & C Nuclear Co.

### AEC Publishes Massive Compendium on Fallout

A 610-page, four-volume encyclopedia on fallout called "Environmental Contamination from Weapons Tests" (HASL-42) has been published by AEC's Health and Safety Laboratory. Subtitled "A Compilation of Data Concerning Transport, Deposition, Distribution and Biological Uptake of World-Wide Radioactive Fallout," its first two volumes contain compilation of fallout-monitoring results, particularly on strontium-90 and cesium-137; the last two contain bibliographies and papers not in the open literature. The work seeks to bring up to date the massive fallout hearing record published by the Joint Committee last year. It is not yet, but will soon be, on public sale.

## NUCLEONICS Statistics of the Month




| | Latest month | Month ago | Year ago |
|---|---|---|---|
| **Nuclear Contracts *—** | | | |
| Contracts awarded for federal projects ($10³) | 10,501 | 7,418 | 2,399 |
| Proposed construction, privately-owned ($10³) | 0 | 0 | 11,000 |
| Contracts awarded, private work ($10³) | 1,000 | 0 | 910 |
| Backlog of private projects ($10⁶) | 249 | 249 | 204 |
| **Access Permits †—** | | | |
| Access permits issued | 24 | 14 | 27 |
| Total access permit holders | 1,417 | 1,410 | 1,327 |
| **Isotope Use †—** | | | |
| Applications for isotope use | 512 | 578 | 451 |
| Cumulative total of isotope users | 3,790 | 3,750 | 4,109 |
| Oak Ridge National Laboratory shipments | 1,282 | 1,306 | 1,187 |
| Public and private export shipments | 286 | 238 | 82 |
| **Employment †—** | | | |
| AEC employment | 6,815 | 6,905 | 6,823 |
| Construction and design contractors' employment | 10,328 | 10,265 | 14,369 |
| Total operating contractors' employment | 113,686 | 113,355 | 98,176 |
| Production workers | 51,400 | 51,848 | 50,525 |
| Research and development employees | 45,087 | 44,760 | 40,780 |
| Miscellaneous workers | 6,871 | 6,482 | 6,871 |

| | Operating | Building | Contracted |
|---|---|---|---|
| **U. S.-built Reactors ‡—** | | | |
| Power, domestic | 1 | 6 | 8 |
| Power, for export | 0 | 1 | 2 |
| Power experiments and pilot plants | 7 | 4 | 1 |
| Military and naval | 5 | 23 | 10 |
| Research and test, domestic | 45 | 22 | 39 |
| Research and test, for export | 8 | 13 | 7 |
| **Foreign-built Reactors ‡—** | | | |
| Power, domestic | 5 | 25 | 11 |
| Power, for export | 0 | 0 | 2 |
| Research and test, domestic | 28 | 14 | 10 |
| Research and test, for export | 6 | 6 | 1 |

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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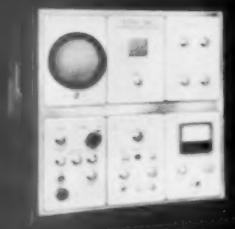

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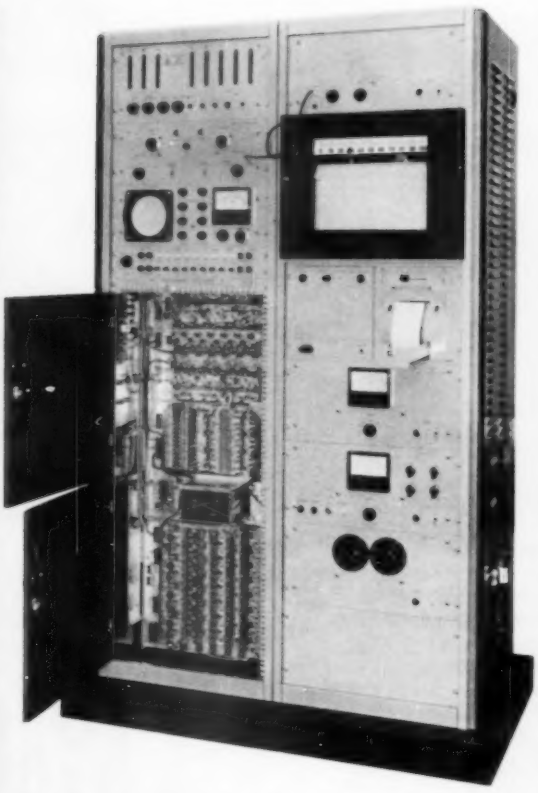

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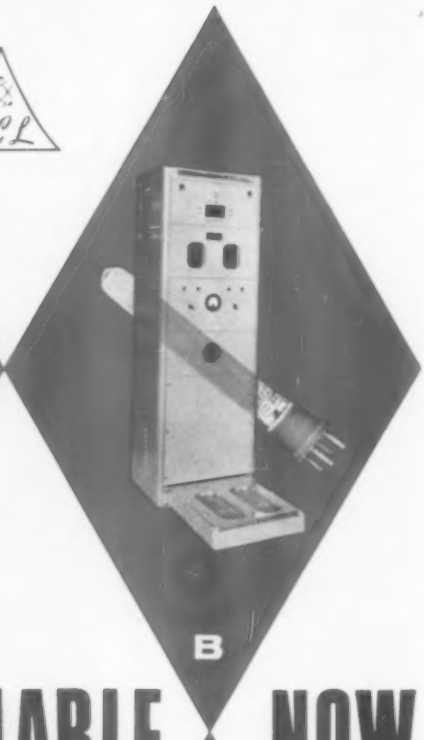


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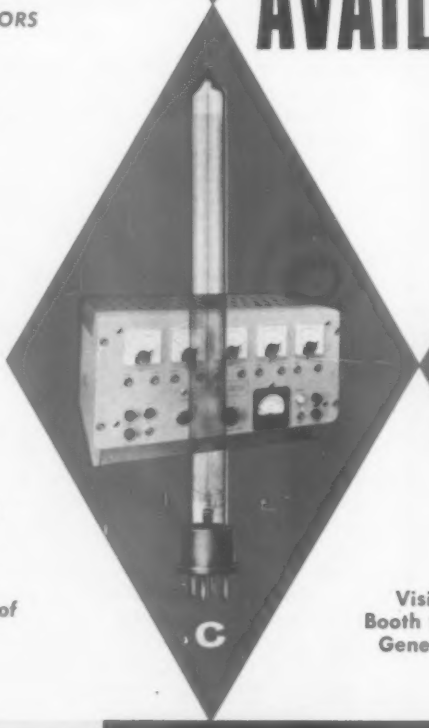


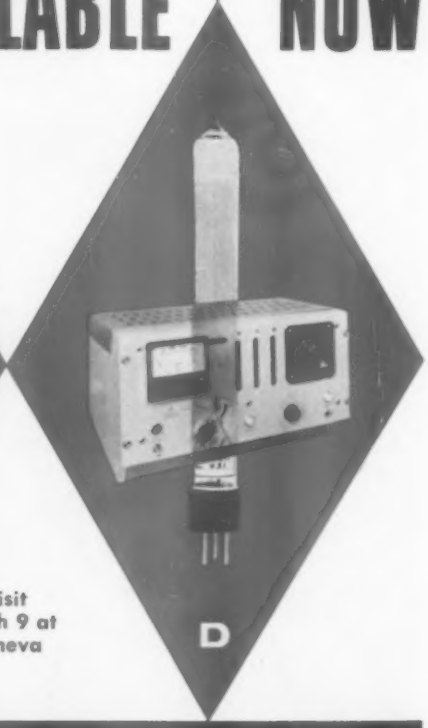


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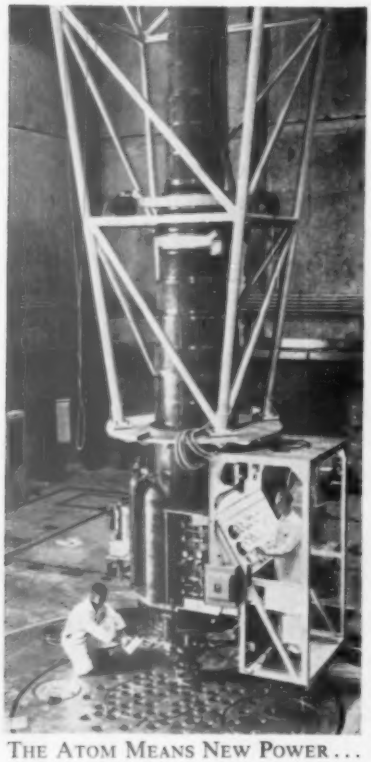


THE ATOM MEANS NEW POWER...
The Sodium Reactor Experiment in California put nuclear electricity into everyday use in San Fernando Valley.

energy is already used by many American housewives at the flick of a switch.

Atomics International is helping to accelerate this rapid advance into the atomic age.

**Sodium reactor successful**

On July 12, 1957—just fifteen years after Fermi's first chain reaction—electricity began to flow from the Sodium Reactor Experiment (SRE) to homes in the San Fernando Valley. It was America's first private-utility power for consumer use from a non-military nuclear reactor.

Atomics International built and operates the SRE for the Atomic Energy Commission. Soon a great new 75,000 kw power station will rise from the plains of the Middle West. Its heart will be a Sodium Graphite Reactor based on the SRE, built under AEC contract by AI for Consumers Public Power District of Nebraska.

**OMRE exceeds expectations**

Another AI power reactor project for the AEC is the Organic Moderated Reactor Experiment (OMRE), which has been in operation since September 1957. The highly satisfactory performance of the OMRE has clearly demonstrated the technical and economic suitability of this reactor type for immediate use to generate electrical power. Construction of the first Organic Moderated Reactor central power station will begin shortly at Piqua, Ohio. Nuclear ship propulsion studies indicate another promising use for the Organic Moderated Reactor.

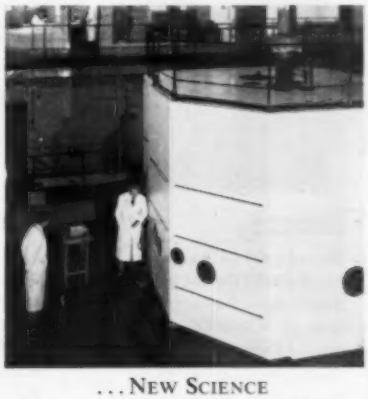
**Important new concept**

Southwest Atomic Energy Associates, a group of fifteen investor-owned utility companies in seven states, have signed a multi-million dollar contract with Atomics International to develop a new type of power reactor—the Advanced Epithermal Thorium Reactor (AETR). Studies are directed to a target plant capacity of 200,000 kw.

...NEW TECHNIQUES
AI's Laboratory Reactors—safe and versatile—under construction for universities, laboratories, and hospitals.

**Atoms across the sea**

More and more countries are launching nuclear power development programs. Atomics International has supplied research reactors for nuclear development to Japan, Denmark, West Germany, West Berlin, Italy. A low-cost Laboratory Reactor for university training, compact and simple to operate, is also available from AI.



...NEW SCIENCE
In The University of Frankfurt, West German scientists and students work with the research reactor, built by AI.

ATOMICS INTERNATIONAL, P.O. BOX 309, Canoga Park, Calif. Cable address: ATOMICS.

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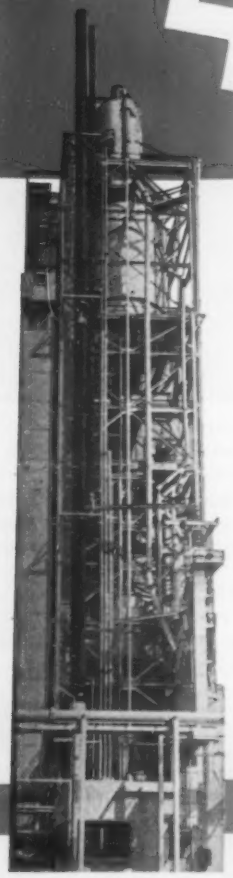
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM

# HOW 41 MAJOR REFINERIES



Catalyst erosion of lift pipes and catalyst handling lines no longer is a problem with refineries listed below. All have eliminated a costly maintenance bottleneck and speeded up turnaround operations by using "Dual Metal."

In making a "Dual Metal" lift pipe the outer shell of weldable alloy steel is poured into a rapidly rotating mold. At the proper time and temperature the abrasion-resistant alloy iron core is introduced. The metallurgically bonded two metal structure combines the strength and weldability of low alloy steel with the superior abrasion resistance of alloy iron.

In one typical refinery, "Dual Metal" high temperature catalyst pipe showed an abrasion resistance of better than 16 to 1 over conventional steel piping.

"Dual Metal" may be the answer to *your* abrasion problem. Write today for literature and information on the increasingly important part this time and money saving process is playing in the refining industry.

## THESE LEADING REFINERIES

| COMPANY | ADDRESS | TYPE UNIT | COMPANY | ADDRESS | TYPE UNIT |
|---|---|---|---|---|---|
| Socony Mobil Oil Co., Inc. | Trenton, Michigan | TCC 75 | General Petroleum Corp. | Torrance, California | TCR |
| Socony Mobil Oil Co., Inc. | Brooklyn, New York | TCC 75 | Magnolia Petroleum Co. | Beaumont, Texas (3) | TCC 75 |
| Socony Mobil Oil Co., Inc. | East Chicago, Indiana | TCC 75 | | (1) | TCC T-5 |
| Socony Mobil Oil Co., Inc. | Buffalo, New York | TCC 75 | | (1) | TCR |
| Standard-Vacuum Refining Co. (Australia) | Altona, Australia | TCC 75 | Phillips Petroleum Co. | Woods Cross, Utah | TCC 45 |
| Socony Mobil Oil Co., Inc. | Augusta, Kansas | TCC 75 | Phillips Petroleum Co. | Okmulgee, Oklahoma | TCC 45 |
| Socony Mobil Oil Co., Inc. | East St. Louis, Illinois | TCC 75 | Continental Oil Co. | Westlake, Louisiana | TCC 60 |
| Socony Mobil Oil Co., Inc. | Paulsboro, New Jersey | TCC 75 | Continental Oil Co. | Westlake, Louisiana | TCC 75 |
| Mobil Oil Company, Ltd. | Coryton, England | TCC 60 | Delta Refining Co. | Memphis, Tennessee | TCC 20 |
| Mobil Oil Italiana S.p.A. | Naples, Italy | TCC 75 | Pontiac Eastern Corp. | Purvis, Mississippi | TCC 100 |
| General Petroleum Corp. | Ferndale, Washington | TCC 100 | Neste Oy | Naantali, Finland | TCC 45 |

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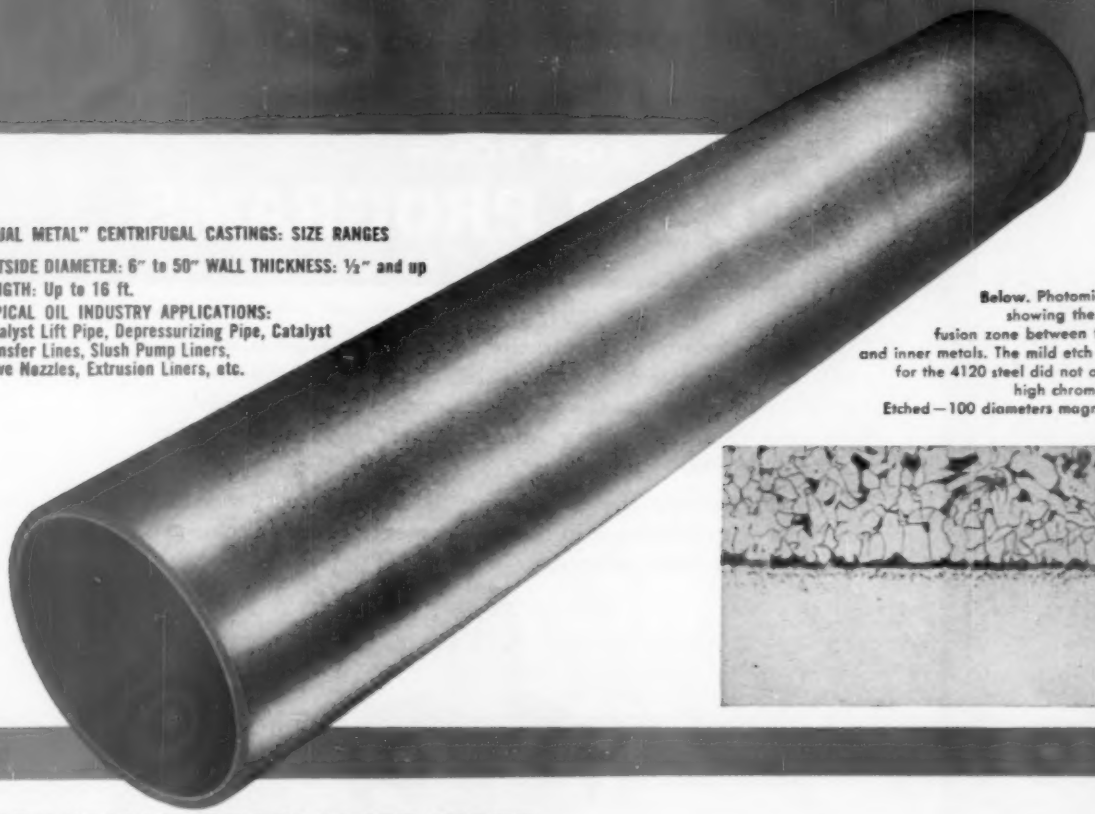
# SAVE MONEY ON TURNAROUND

**"DUAL METAL" CENTRIFUGAL CASTINGS: SIZE RANGES**

**OUTSIDE DIAMETER: 6" to 50" WALL THICKNESS: ½" and up**
**LENGTH: Up to 16 ft.**
**TYPICAL OIL INDUSTRY APPLICATIONS:**
**Catalyst Lift Pipe, Depressurizing Pipe, Catalyst Transfer Lines, Slush Pump Liners, Valve Nozzles, Extrusion Liners, etc.**



**Below.** Photomicrograph showing the bond or fusion zone between the outer and inner metals. The mild etch required for the 4120 steel did not attack the high chromium iron. Etched—100 diameters magnification.

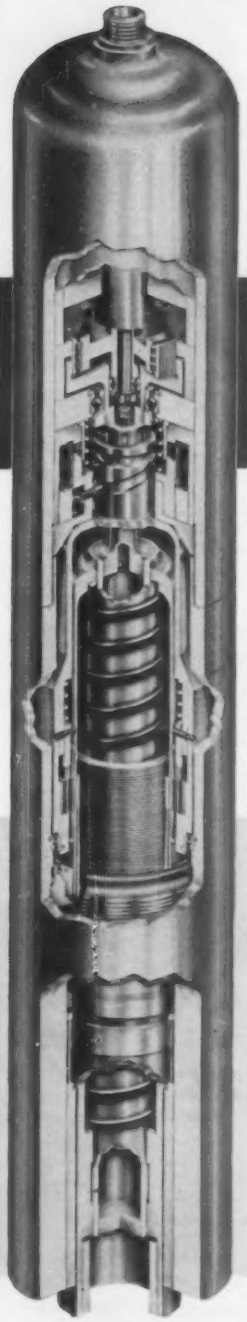
## USE "DUAL METAL" LIFT PIPES

| COMPANY | ADDRESS | TYPE UNIT |
|---|---|---|
| "ALBATROS" Societé Ananyme Belge pour le Raffinage de Pétrole | | |
| Installations Pétrolifères | Anvers-Kiel, Belgium | Houdriflow |
| The California Oil Company | Perth Amboy, New Jersey | Houdriflow |
| Texas City Refining, Inc. | Texas City, Texas | Houdriflow |
| Commonwealth Oil Refining Co., Inc. | Ponce, Puerto Rico | Houdriflow |
| Salt Lake Refining Co. | Salt Lake City, Utah | Houdriflow |
| Pure Oil Co. | Smith's Bluff, Texas | TCC |
| The Shamrock Oil & Gas Corp. | Sunray, Texas | Houdriflow |
| Purfina Italiana S.p.A. | Rome, Italy | TCC 11 |
| | Genoa, Italy | TCC 11 |

| COMPANY | ADDRESS | TYPE UNIT |
|---|---|---|
| Bay Refining Corp. | Bay City, Michigan | TCC 33 |
| Hancock Oil Co. | Long Beach, California | TCC 40 |
| Chinese Petroleum Corporation | Taiwan (Formosa) China | TCC 45 |
| CONDOR S.p.A. Societa' per L'Industria Petrolifera e Chimica | Milan, Italy | TCC 75 |
| The Standard Oil Co. (Ohio) | Cleveland, Ohio | TCC 75 |
| Great Northern Oil Company | St. Paul, Minnesota | TCC 100X |
| American Petrofina, Inc. | Mt. Pleasant, Texas | TCC 60 |
| Refinaria e Exploracao de Petroleo Uniao S.A. | Capuava, Brazil | TCC 120 |
| Turkiye Petrolleri A.O. | Batman, Turkey | TCC 20 |
| Erdol-Raffinerie Emsland | Lingen, Germany | Houdriflow |

Cross-section view of dual metal piping consisting of a weldable SAE 4120 steel outer shell and a metallurgically bonded inner layer of high carbon-high chromium abrasion resisting iron. Photograph actual size. Composition of the hard inner layer:

| C | Mn | P | S | Si | Cr |
|---|---|---|---|---|---|
| 2.85 | 1.10 | .009 | .023 | .85 | 29.36 |



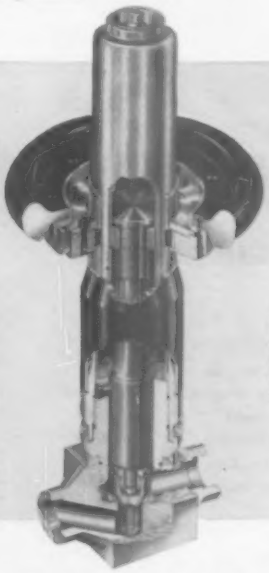
# Reactor Components Systems

## FOR YOUR NUCLEAR PROGRAMS

United . . . a reliable subcontractor for control rod drive mechanisms, refueling systems, valve actuators and special remote operating equipment . . . offers the experience, special skills and complete integrated facilities of their Atomic Power Department to the nuclear industry — and to you.

We would welcome the opportunity to discuss your particular problems or requirements in the development of reactor components for your nuclear programs.

Hermetically sealed control rod drive mechanism using a 60 cycle power supply to meet U. S. Navy requirements.



1 inch globe valve with a hand operated United Harmonic Drive actuator. The actuator is adaptable to motorized operation.

### CONTROL ROD DRIVE MECHANISMS

In addition to design, development and manufacture of control rod drive mechanisms to your submitted specifications . . . United's continuing research has resulted in the development of the United Harmonic Drive principle — a method of transmitting power through steel walls by controlled deflection waves that produces positive linear motion. Using the new principle, the control rod drive mechanism wall is deflected within endurance limits of suitable materials, engaging the lead screw and actuating the control rod. The United Harmonic Drive principle gives precise motion control with positive position indication and offers mechanism and system cost savings.

### HERMETICALLY SEALED VALVES

United's Harmonic Drive principle has also been applied to valve actuation. The new principle uses a United Harmonic Drive linear actuator to position the valve plug. Test results on a hermetically sealed valve for design pressures up to 3000 p.s.i. at 600°F have proven reliability. United Harmonic Drive is readily adaptable for a wide range of valve sizes.

*RESEARCH . . . DESIGN . . .*

## REFUELING SYSTEMS

United's experience in the design and development of both wet and dry reactor refueling systems includes such projects as submarine reactors, two shipboard reactors and the first large scale commercial nuclear power plant (PWR).

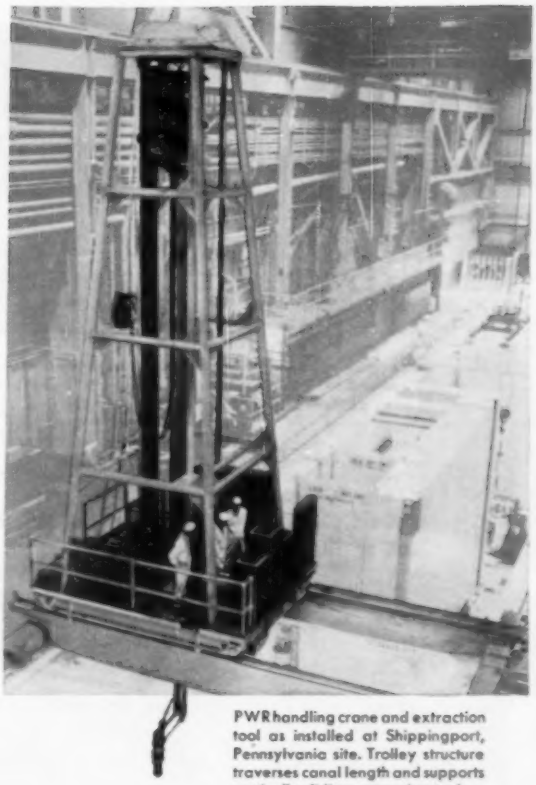
Systems designed and built by United:

Equipment for replacing individual reactor core elements within the submarine Triton's hull.

Manually operated equipment for shipboard reactors using an underwater periscope for positioning. Equipment is segmented for easy installation and storage.

Refueling system for the PWR at Shippingport, Pennsylvania. Remote controlled handling tool is guided down through 30 feet of water, through the vessel head to the hot core. Precisely locates and easily extracts or inserts any of 145 fuel cells . . even those which are offset sharply from one of the 10 access ports.

**WRITE FOR** *illustrated folders that give full information and specific details on the equipment and components shown.*



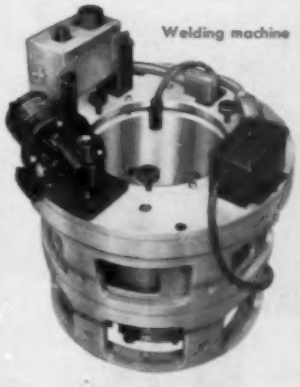
PWR handling crane and extraction tool as installed at Shippingport, Pennsylvania site. Trolley structure traverses canal length and supports vertically sliding extraction tool.

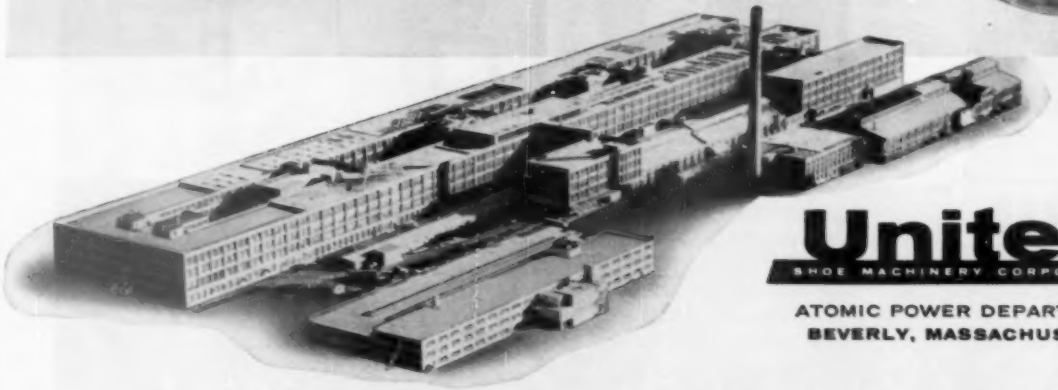
## SEAL WELDING AND CUTTING EQUIPMENT

Cutting machine

The design and development of automatic seal welding and cutting equipment for nuclear reactors is an important activity at United. One such development involved the design and manufacture of cutting and welding equipment using consumable inserts for the U. S. Navy submarine Triton (S4G). Equipment will cut and re-weld 11 inch diameter welds on the control rod drive mechanisms at the various angles. A control unit provides automatic sequencing of welding operations and the design of the welding unit allows use in spaces as close as 1¾ inches from weld to adjacent mechanisms. Equipment can be operated with any or all control drive mechanisms in place and its reliability eliminates the necessity for radiographic inspection.

Welding machine





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### DD-2 NON-OVERLOAD LINEAR AMPLIFIER

**Model 751** (ORNL Q1593)

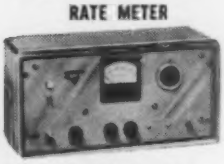
DD-2 Non-Overload Linear Amplifier for scintillation spectrometry, reactor control, etc. and other applications requiring high gain, fast resolution, good linearity, and fast overload recovery.

### HI-SPEED SCALER

**Model 762** (ORNL Q1743)

One microsecond Hi-Speed Scaler is designed for counting pulses from nuclear detectors. Permits counting pulses at high rates with extremely low coincidence loss. Use of decade counting circuits increases reliability and gives low power consumption.

### LOGARITHMIC COUNT RATE METER



**Model 727** (ORNL Q1454B)

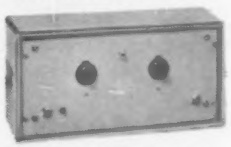
Logarithmic Count Rate Meter. Wide range, five decade instrument for use with all types of radiation detectors. Range 10 to 1,000,000 counts per minute.

### AID LINEAR AMPLIFIER

**Model 672A** (ORNL Q1326)

AID Linear Amplifier. Amplifies low level signal pulses from radiation detectors such as ionization chambers, proportional and scintillation counters.

### SINGLE CHANNEL DIFFERENTIAL ANALYZER



**Model 695** (ORNL Q1192)

Single Channel Differential Analyzer. A differential pulse height analyzer for separating pulses of varying amplitudes.

### HIGH VOLTAGE POWER SUPPLIES

**Model 683**

Ultra-Stable Hi-Voltage Power Supply. Stable and regulated power supplies of all types for precision scintillation spectrometry as well as Geiger and proportional counting. Continuously variable over wide range of voltages.

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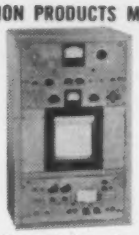
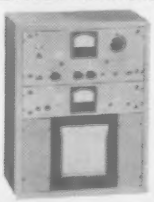
Portable continuous air particle monitoring units to latest ORNL specifications.

### FISSION PRODUCTS MONITORS



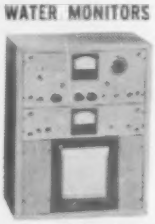
A reliable monitoring system based on MTR design at Idaho Falls for detection of fission product activity in coolant stream.

### NEUTRON MONITORS



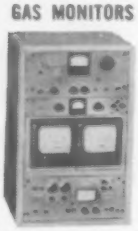
Fast and thermal neutron monitoring systems designed for bulk shielding and dosimetry studies.

### WATER MONITORS



For monitoring radioactive liquids in pipes, pools and streams or other locations.

### GAS MONITORS



Designed for continuous monitoring of radioactive stack gases. Contains built-in alarm system to operate external control circuits.

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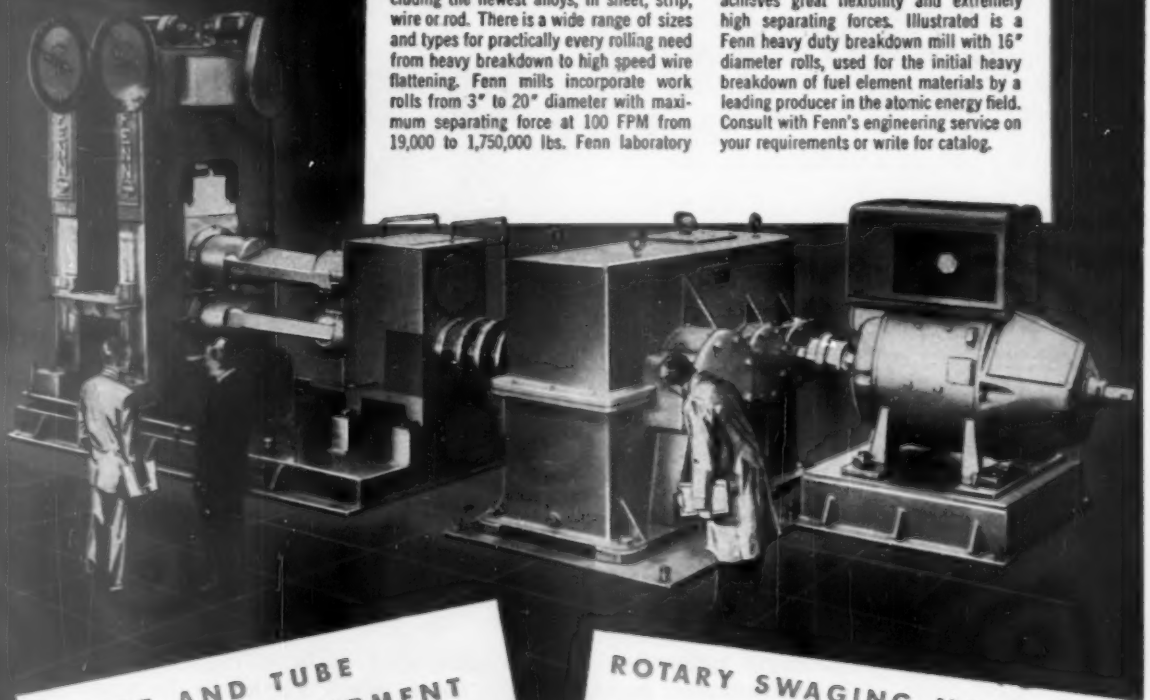
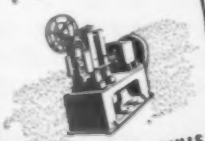


WIRE AND TUBE FORMING EQUIPMENT



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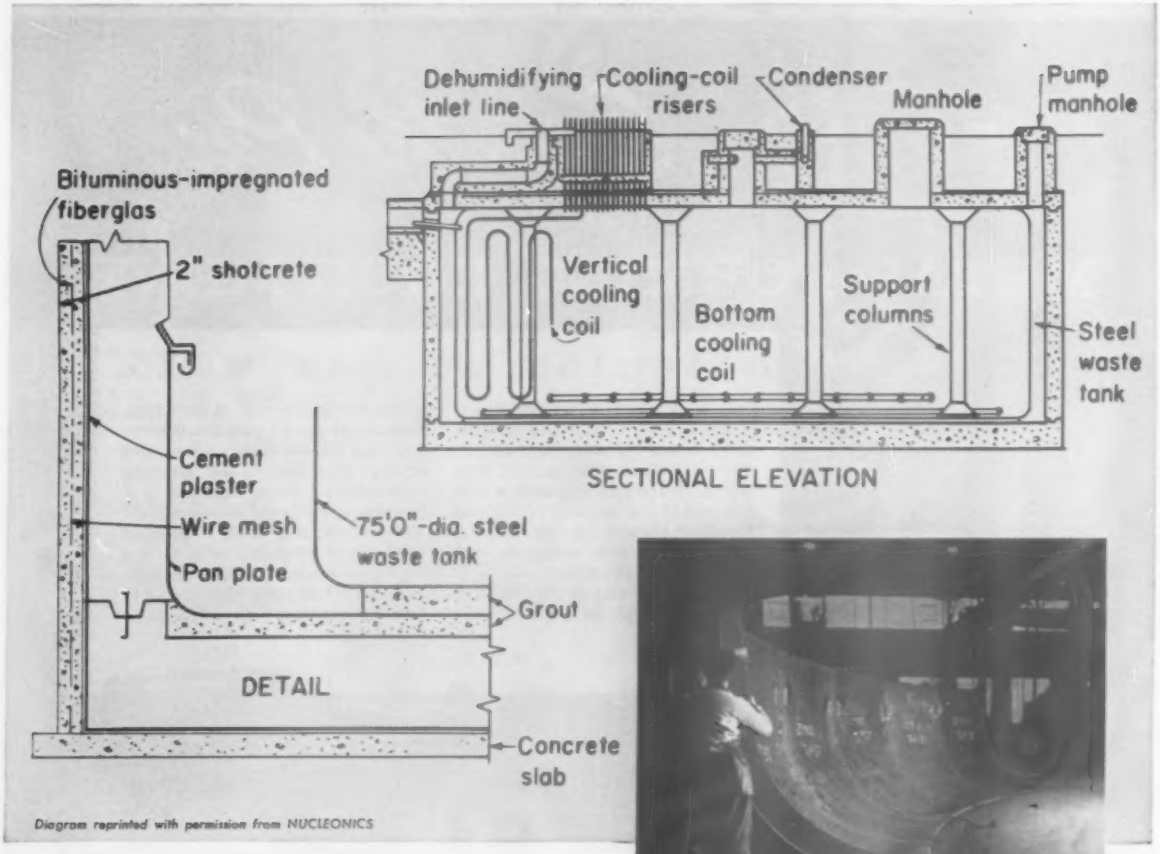

# One AEC Solution To Radioactive Waste Storage

Storing radioactive wastes underground in huge 750,000 gallon double-bottomed steel tanks, as shown above, is one solution to the waste disposal problem at the AEC installations at Savannah River, S. C. and Hanford, Wash. Internal cooling coils take away the heat generated by radioactive decay. Remote handling protects personnel from high activity levels.

Graver has fabricated and erected sixty-eight such waste storage tanks for these nuclear installations. Special fabricating methods and field-erection techniques were required. For example, shop fit-up of the curved bottom plates expedited field assembly of the tanks.

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Frankly, we're not certain just where this versatile material might fit into your program. We do know that Alite has proven useful in various reactor structural components and as a crucible material for processing various reactor materials. If you would like to explore the possibilities of applying Alite to your nucleonic design problems, our ceramics specialists will be happy to study your requirements and assist you in every way possible.

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• Pulse Height Selector: Resolving time, 1.2 microseconds; 0-100 volt base line with 50 millivolt per day stability; 0-10 volt window with 1% stability at 1 volt; rate dependence, less than 10 millivolts window shift at 200,000 C.P.S.

• Combination provides the ultimate in reliability and stability. Designed to handle most pulse amplification and height analysis problems encountered in the nuclear field today.

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• Unmatched stability against line change; less than 0.003% per volt—Regulation, 0.0025% per MA @ 1000 volts—Output impedance, 2.5 ohms.

• Low noise and ripple; less than 1 MV RMS.

• Designed for use with scintillation and proportional counters or for general laboratory use—anywhere the ultimate in stability is required at a reasonable price.

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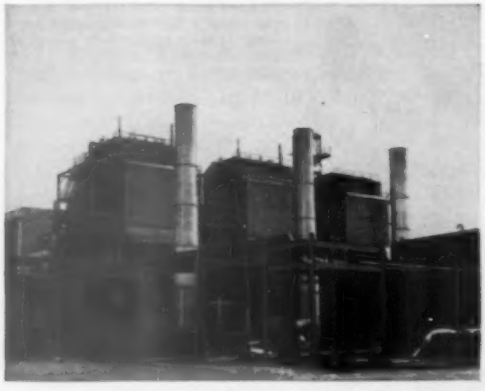

960,000 pounds/hour steam generator plant producing process steam, compressed air and 31,250 KW of electricity for alumina plant. Designed and built by KE.

A 475,000 KW power plant in Louisiana. America's Engineering Test Reactor in Idaho. A 100,000 KW industrial steam power plant in Pennsylvania. The engineering study for the AEC's Gas Cooled Graphite Moderated Power Reactor. A $10,000,000 dual-purpose process steam and power plant. New nuclear development projects in Europe, Asia and Latin America. This is Experience—electric power from both nuclear and fossil fuels. To which Kaiser Engineers couples Ingenuity to pioneer, to develop new methods, to achieve better plants, quicker, for less. For experience, ingenuity, and a cost conscious approach, call or write KE. Today.

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# if it has to do with isotopes

in INDUSTRY

## industrial radiography

Picker makes and markets radiographic equipment using Cesium 137, Cobalt 60, Iridium 192 and Thulium 170. Various units safely contain isotope sources ranging from *millicuries* to *kilocuries* with radiation-yields up to 1,000 RHM. Apparatus size ranges from lightweight portable models up to the massive *CYCLOPS* you see here. Each is selfcontained: requires no power or water lines.

Simultaneous one-shot radiography of multiple castings Tech/Ops Iridium 192 unit.

A single exposure radiographs entire girth weld of thick stainless steel casting. Tech/Ops Cobalt 60 Unit.

The 1,000 RHM output of the Picker *CYCLOPS* Cobalt 60 Mobile Unit can radiograph steel up to a foot thick (sections 6 inches thick take only 15 minutes).

## encapsulation and hot cell work

*Picker is prepared to*

*encapsulate large or small sources*
(Cobalt 60, Cesium 137, Iridium 192) in shapes and yields tailored to your needs.

*provide custom-built or standard irradiators*
(like the HOTPOT here) for use in research laboratories.

*test-irradiate your materials*
in our own hot cell at standard charges based on total "dose" delivered.

Picker Cobalt 60 *HOTPOT* flux can reach a million roentgens per hour. It is no bigger than a desk and safe enough to keep in your laboratory or office.

Picker x-ray

Briefed above are some ramifications of Picker isotope facilities. Any local Picker office will be glad to work with you concerning any phase of these inclusive services. Or write us . . .

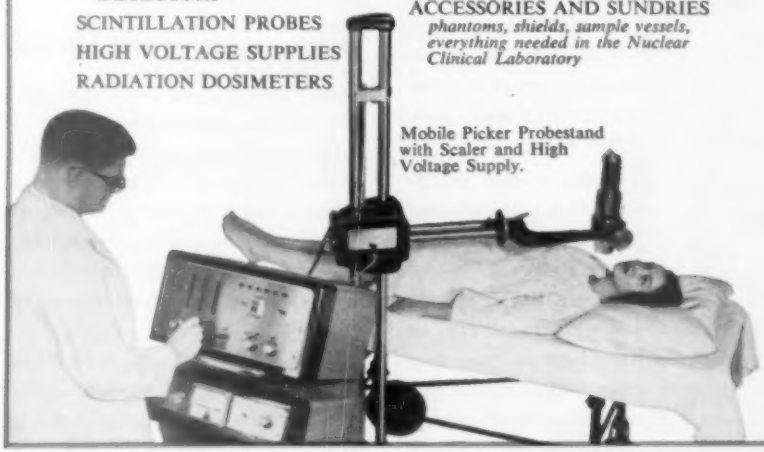
Picker X-Ray Corporation, 25 South Broadway, White Plains, N. Y.
Picker X-Ray Engineering, Ltd., 1074 Laurier Ave. W., Montreal, Canada
Picker International Corporation, 19 South Broadway, White Plains, N. Y.

# it has to do with PICKER

## nuclear instrumentation

The Picker hallmark on Nuclear Instruments is dependable assurance of up-to-date apparatus soundly designed, well made and backstopped by the trained Picker service organization with local service depots everywhere.

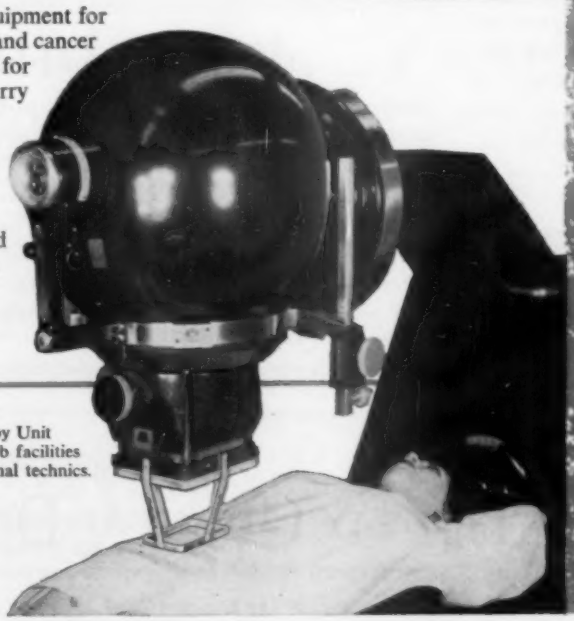
- DECADE SCALERS *with or without pulse-height discrimination*
- RATEMETERS
- WELL-TYPE SCINTILLATION DETECTORS
- SCINTILLATION PROBES
- HIGH VOLTAGE SUPPLIES
- RADIATION DOSIMETERS
- RADIATION SURVEY METERS
- SPECTROMETERS
- SCINTILLATION SCANNERS
- MOBILE SUPPORTS FOR PROBES AND INSTRUMENTS
- ACCESSORIES AND SUNDRIES *phantoms, shields, sample vessels, everything needed in the Nuclear Clinical Laboratory*



Mobile Picker Probestand with Scaler and High Voltage Supply.

## equipment for radiation therapy

You'll find Picker Isotope Equipment for radiation therapy in hospitals and cancer centers the world over. Units for Cesium 137 and Cobalt 60 carry sources of 1,000, 2,000, or 3,000 RHM in ceiling-hung or vertical floor stand or rotating yoke supports. All highly regarded for the easy positioning-to-patient and dosage-accuracy they provide.



Picker C-1000 Cobalt 60 Therapy Unit on rotating yoke support. Superb facilities for either fixed beam or rotational technics.

*advertisement*

# RARE EARTHS AS NUCLEAR POISONS

## *Cost and availability are no longer problems*

a report by LINDSAY

Significant developments in the cost and availability of the neutron absorbing rare earths are redirecting the attention of control rod designers to the use of these materials as poisons in nuclear reactors.

Early interest in the rare earths was centered in europium because of its superb neutron absorbing properties and extended life. At that time, *all* the high cross section rare earths were scarce and expensive, and the metallurgical problems were relatively unexplored.

### PRODUCTION FROM ION EXCHANGE

Since then, considerable experimental work has been devoted to development of practical fabricating techniques and the improvement of separation processes. Lindsay pioneered the first commercially installed ion exchange plant for the production of rare earth oxides in purities up to 99.99%.

Now, more than 100 columns with large production units of eighteen inch and sixty inch diameters are in continuous operation at the Lindsay plant. All the important neutron absorbing rare earths are now available, not only as the oxide which can be custom made with regard to density and particle size, but also as the boride, disilicide, or metal.

One important by-product of the advances in separation technology is that several of the rare earth absorbers have become common materials. The prices of oxides of gadolinium, samarium, erbium, dysprosium and europium have all tumbled sharply. Only europium is priced above $1 per gram; samarium and gadolinium are but a few cents per gram.

We know of course that europium is the most effective control rod material, but because of its scarcity, it will always be the most expensive rare earth absorber. Control rod designers now need to consider price, as well as properties, when selecting rare earth materials as control rod poisons.

Except in high flux reactors requiring few control rods, it is uneconomic to use europium as a primary poison; most commercial reactors do not need it except for its ability to absorb epithermal neutrons. Therefore, we suggest that control rod designers concerned with fluxes of about $2 \times 10^{13}$ consider gadolinium as their primary poison, with samarium, dysprosium, erbium, or europium as additions to achieve desired rod worth. *Where both cost and performance are factors, the rare earths are no longer exotic, but actually superior to other materials.*

Furthermore, the prices quoted for certain mixtures of the rare earths may be well below those quoted for each material separately.

### AMPLE CAPACITY TO MEET DEMAND

Lindsay has expanded production facilities and has ample capacity to meet anticipated demand for neutron poisons in the foreseeable future. Our technical staff is familiar with both control rod and rare earth separation technologies, and is available to help you select the most economical mixture of materials.

We have a wealth of technical data and ideas relating to the use of various rare earths in control rods, some of which is contained in our brochure "Rare Earths as Poisons in Nuclear Reactors." A copy is yours for the asking.

## THORIUM . . . *a superior fertile material*

Lindsay is the world's largest producer of *both* rare earth and thorium chemicals. Thorium and thorium oxides are being used and proposed more and more in new reactors in spite of the temptation to use uranium in order to capitalize on the temporary high buy back price for Pu. Thorium materials, particularly the metal, can operate at higher thermal conditions than their uranium counterparts, and show a somewhat higher thermal conductivity. The $\eta$ for $U^{233}$ is much higher at thermal neutron energies than $\eta$ for any other fuel; the Th-$U^{233}$ cycle is the best hope for breeding in thermal reactors.

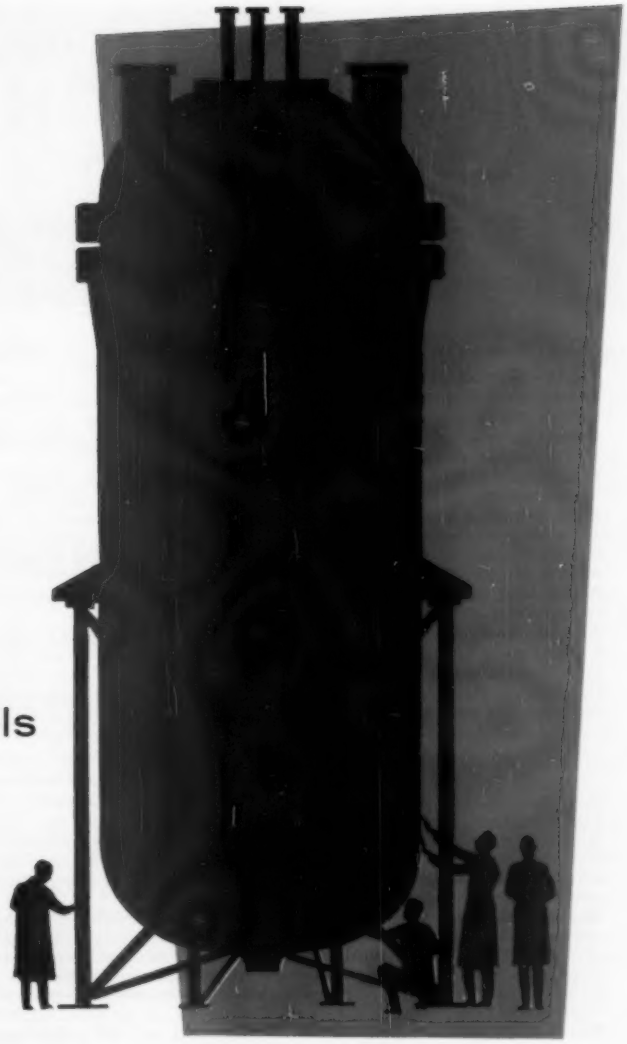
PLEASE ADDRESS INQUIRIES TO

TRONA

LINDSAY CHEMICAL DIVISION

*American Potash & Chemical Corporation*

272 Ann Street, West Chicago, Illinois



In the design,

engineering

and fabrication

of Pressure Vessels

for Nuclear

Reactors

# one stands out... PACECO

Designers, Builders, Buyers of nuclear power plants! PACECO offers design-engineering experience and fabricating skills with reactor pressure vessels unmatched by any other company in the world. PACECO has been a part of virtually every project of the Atomic Energy Commission since 1947. PACECO designed and built the boiling water reactor vessel for the world's first privately financed nuclear power plant. One of the world's first aluminum reactor vessels was built by PACECO for General Electric... And PACECO is now at work on a 77 ton test reactor vessel for Westinghouse Electric Co.'s facility at Waltz Mills, Pennsylvania. This is a record of achievement and experience which stands out in the infant industry of commercial atomic power. Here at PACECO is a fund of nuclear knowledge from which architect-engineers, contractors and utilities can profitably draw.

For more information about PACECO's services and facilities write for Brochure 8-A

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# leading reactor builder offers

# LONG RANGE CAREERS

## in worldwide nuclear projects

### EXPERIENCED NUCLEAR ENGINEERS

### ANALYTICAL

Degree essential. Experience as required.

**Preliminary Engineering:** Conduct preliminary analysis and design of overall power reactor systems and components.

**Core Analysis:** Includes criticality, temperature, void and power coefficients, control effectiveness and fuel cycles.

**Shielding Analysis:** Advanced studies and analysis on stationary and mobile plants.

**Heat Transfer and Fluid Flow:** Steady-state and transient analysis. Includes power optimization studies, free and forced convection flow transients, boiling, and two phase flow. Advanced analytical methods using analog and digital computers.

**Stress Analysis:** Structural, thermal, and dynamic stress analysis of high temperature reactor systems.

**Systems Analysis:** Coordinate engineering on reactor plant design.

**Control Analysis:** Reactor kinetics and overall nuclear power plant control – hazard analysis – analog and digital computers.

**Operations:** Foreign and domestic – for check-out, start-up and customer training. Includes operational analysis and design criteria.

### DEVELOPMENTAL

Requires related experience and applicable degree.

**Fuel Elements:** Experienced senior physical metallurgists for responsible positions in nuclear reactor fuel development programs. Includes studies of radiation effects, overall evaluation of uranium and thorium alloy, and ceramics. Also metallurgical engineers for mechanical fabrication development for these materials.

**Mechanical Components:** Experienced mechanical engineers for the development of coolant and other equipment for power reactors. Stimulating developmental problems in thermodynamics, stress, heat transfer and fluid dynamics. Senior metallurgists for responsible research positions on reactor structural materials. Desire alloy development and solid state diffusion experience.

**Instrumentation and Control:** Senior physicists and EE's for design and development of advanced design transistor, vacuum tube, and/or magnetic amplifier control and instrumentation components.

### DESIGN

Senior opening. Degree required. Nuclear experience essential.

**Process Instrumentation:** Reactor, auxiliary, and control systems.

**Facilities:** Mechanical systems.

**Process Systems and Equipment:** Pumps, heat transfer equipment.

**Electrical:** Reactor control and power systems.

**Machine Design:** Heavy mechanical.

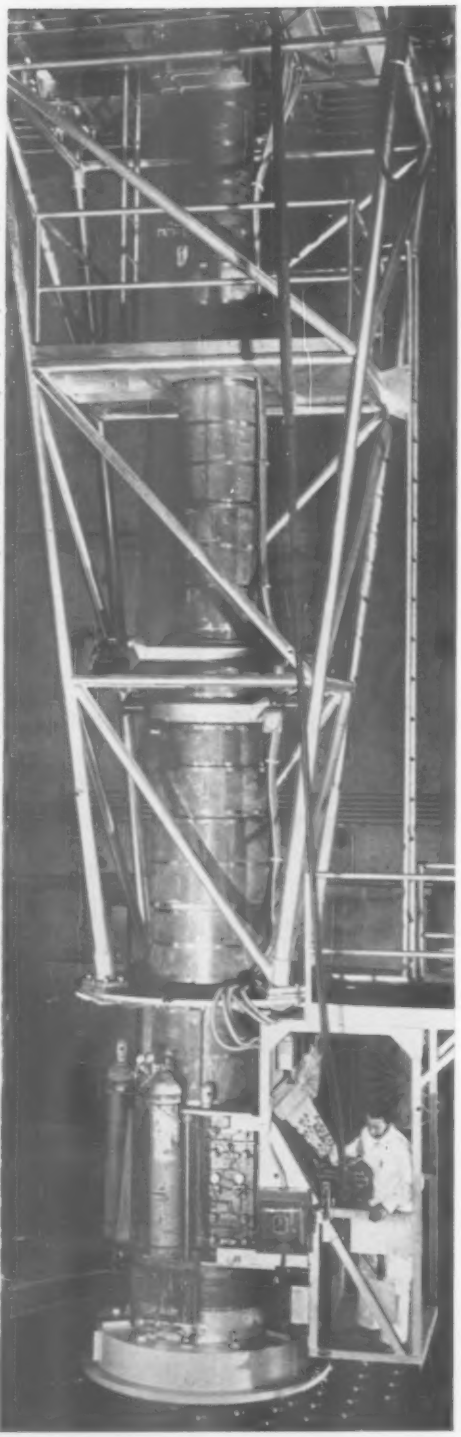
**Reactor Core Components:** Moderator cans, fuel elements, core supporting structures.

**Control Mechanisms:** Control and safety rods, drives and allied tooling.

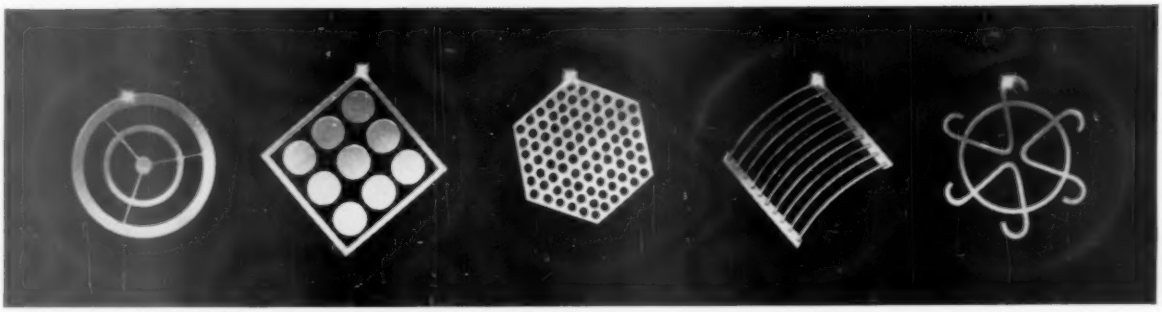
**Other opportunities in:**
Reactor Theory, Experimental Neutron Physics,
Solid State Physics, and Reactor Kinetics.

Write for more details of exciting career opportunities at AI.
Mr. C. H. Newton, Personnel Office, Atomics International,
15330 Raymer Street, Van Nuys, California.
(In the suburban San Fernando Valley, near Los Angeles)

**ATOMICS INTERNATIONAL**
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM



**SRE Fuel Handling Cask.** The Sodium Reactor Experiment and the Organic Moderated Reactor Experiment are both in successful operation. Plans for several central station plants based on these experimental power reactors are underway. AI is also conducting an advanced power reactor study for Southwest Atomic Energy Associates. Overseas, AI has already sold 5 reactors, and is affiliated with ASEA of Sweden and the new company INTERATOM (with DEMAG, West Germany).



**Reactor builders and operators:**

# Save time and money

**with**

# Sylcor "package fuel"

**Once you obtain the allocation, we do the rest... right through the final delivery of the completed high-integrity elements.**

Our pioneering nuclear "package fuel" plan can save you time and money . . . and completely eliminate your involvement in the many necessary stages of fuel manufacture.

Here is how this remarkably simple plan works:

- We will quote you one fixed price. This is the *total* and *only* charge to you for the delivery of the completed fuel elements ready for core loading.
- You need only obtain an allocation for the particular nuclear material specifically required in your fuel. Under our plan, there is no need to get the usual extra allocation to cover scrap and losses in the production of standard enrichment fuels.
- We will do all the arranging and will pay for the conversion of $UF_6$.
- If you need rapid delivery, we will supply from our inventory all special nuclear material, replacing this material from your allocation before delivery of fuel elements.
- We will assume responsibility for all scrap reprocessing and processing losses.
- We will pay all of the use charges during the entire fuel element production period. You assume direct-use charges on only the special nuclear material in your fuel elements, and only after delivery of the completed fuel elements.

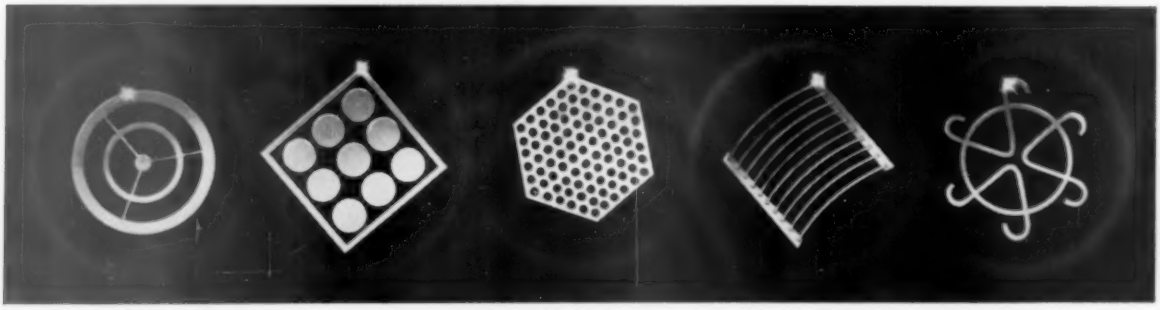
Let our experienced staff of engineers, scientists and technicians help you. Our facilities are devoted exclusively to the design, fabrication and processing of nuclear fuels. As a result, we have produced more reactor fuel elements than any other commercial facility in the free world.

To find out more about our "package fuel" plan, and about our facilities for helping you, write for descriptive literature to Sylvania-Corning Nuclear Corporation, Bayside, New York. And, for a copy of "Bibliography on Solid Fuel Elements" write to us on your company letterhead.

SYLCOR

SYLVANIA–CORNING NUCLEAR CORP.

*See the SYLCOR display at the Atoms-for-Peace Exhibition, Geneva*



# Why cyclotron magnet frames are made from forgings

**Man is in a desperate race** to learn more about magnetics. One famous acres-big cyclotron could be reduced to the size of a steamer trunk if they could only find a way to increase the magnetic field strength by 20 times. And already we see evidence that very strong magnetic fields may hold the secret to one of man's most sought-after dreams: sustained nuclear fusion power generation.

But when you double the strength of a magnetic field, the energy density or pressure increases *fourfold*. A not-uncommon 50,000 gauss magnetic field exerts a pressure of about 1,400 psi; but other laboratory experiments have already created fields of 1½ million gauss for a few microseconds, and they confidently expect to hit *10 million* gauss before long!

To contain the fantastic forces, designers of very large electromagnets turn to high-quality forged steel parts, and they very often come to United States Steel to ask for USS Quality Forgings.

The picture shows a cyclotron electromagnet frame that will go into service at Oak Ridge National Laboratory, Oak Ridge, Tennessee. It is made from six USS Quality Forgings that total 193 tons including the two cylindrical pole pieces. The pole pieces are machined to a .005″ flatness, and are parallel to within .005″. These tolerances are essential for close control over the bombarding particle beam—which often operates at velocities which approach 50,000 miles *per second*. All six forgings were melted, forged, machined, heat-treated and inspected right at our Homestead Forgings Division, and we also furnished all dowels (4½″ in diameter), nuts, bolts and lifting eyes.

Many cyclotron and nuclear reactor parts are made from USS Quality Forgings because buyers have learned that they are made from the finest steel, on the most modern equipment, by the most skilled forging men in all the world. No matter what kind or size of USS Quality Forgings you buy, you get the advantage of these same facilities. Please address inquiries or requests for our free forgings booklet to United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

*USS is a registered trademark*

United States Steel Corporation – Pittsburgh
Columbia-Geneva Steel – San Francisco
Tennessee Coal & Iron – Fairfield, Alabama
United States Steel Export Company

USS United States Steel

# ...IS HERE:

***In the training of nuclear scientists,*** the new American-Standard University Training Reactor, UTR-10, is superior to any similar equipment because of a combination of its performance and versatility.

It is not only a source of neutrons for basic research, but also it operates at a sufficiently high power level to demonstrate experiments in advanced studies of engineering principles, showing the generation of heat, circulation of the coolant, processing of the coolant, control rod operation, and control instrumentation. Its high nuclear power and high neutron flux are provided at lowest possible cost.

The UTR's versatility results from the fact that its core is accessible from all sides and by any combination of beam ports, irradiation caves, and isotope facilities.

University use requires—as a prerequisite—complete safety, and the UTR-10 meets this requirement thoroughly because of its foolproof startup system, double scram system, and inherent safety provisions in its design.

You are invited, at your convenience, to inspect the UTR now operating at our Mountain View facilities, where it is being used in the training of reactor operators. Delivery can be made in from three to six months. For price and delivery quotations, write Marketing Department—

369 WHISMAN ROAD
MOUNTAIN VIEW, CALIF.

American-Standard PRODUCTS

**AMERICAN-Standard**

**ATOMIC ENERGY DIVISION**

American-Standard and Standard ® are trademarks of American Radiator & Standard Sanitary Corporation.

# Packard RADIOACTIVITY DETECTION INSTRUMENTS

## Tri-Carb* Liquid Scintillation Spectrometers

Tri-Carb Spectrometers are designed for counting tritium, carbon-14 and other beta-emitting isotopes. Up to 100 5-dram sample vials can be counted at each loading.

Tri-Carb Spectrometers are also available with manual sample chambers. Both automatic and manual models offer all the advantages of liquid scintillation counting—sensitivity, versatility, operational simplicity and ease of sample preparation.

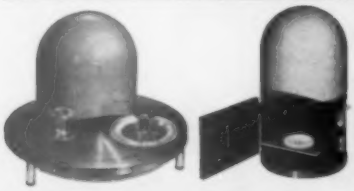
## Auto-Gamma* Sample Changers

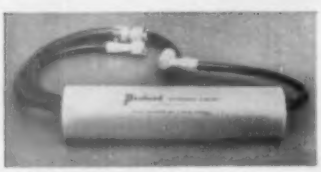
Auto-Gamma Sample Changers are designed for use with standard well-type scintillation detectors. Up to 100 test tubes (16 mm x 150 mm) can be counted at each loading.

Auto-Gamma Sample Changers are available for many different systems. They can be provided as complete units with either large or small sodium iodide crystals. They can also be used with scintillation spectrometers and simple scaler systems.

*Automatic Tri-Carb Spectrometers and Auto-Gamma Sample Changers can be operated 24 hours per day, seven days per week. Operation is on the basis of both preset time and preset count. Counting is stopped by whichever is reached first. Sample number, time interval and scaler readings are permanently recorded on paper tape. Scaler and readout circuits, similar in both instruments, are completely transistorized for utmost reliability.*

**REQUEST LATEST BULLETINS**





## WINDOWLESS and FLO-WINDOW* COUNTERS

**...for geiger and proportional operation**

Windowless Flow Counters provide maximum sensitivity and essentially unlimited life. Full $2\pi$ geometry is achieved.

Flo-Window Counters feature thin plastic windows for minimum absorption. Counting chambers are isolated from the samples so that static charge, vapor effect, contamination, etc. are eliminated.

### Completely Transistorized Proportional Counting Amplifiers

These non-overloading amplifiers are designed for use with proportional counters. They provide a gain of 1100 and are small enough to be conveniently located with the detectors, thus eliminating preamplifiers.

*Trademarks

VISIT US AT ATOMS FOR PEACE INTERNATIONAL EXHIBITION—GENEVA, 1958

**Packard Instrument Company, Inc.**

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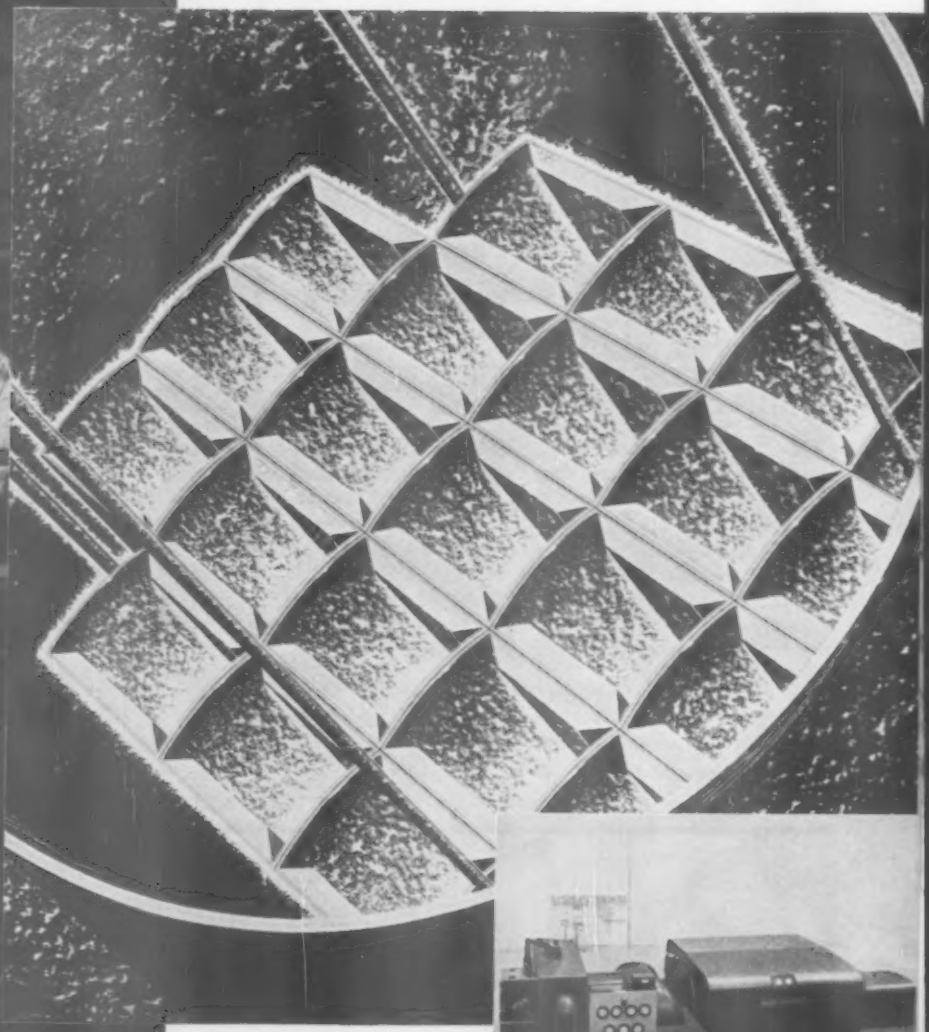
# NUCLEAR



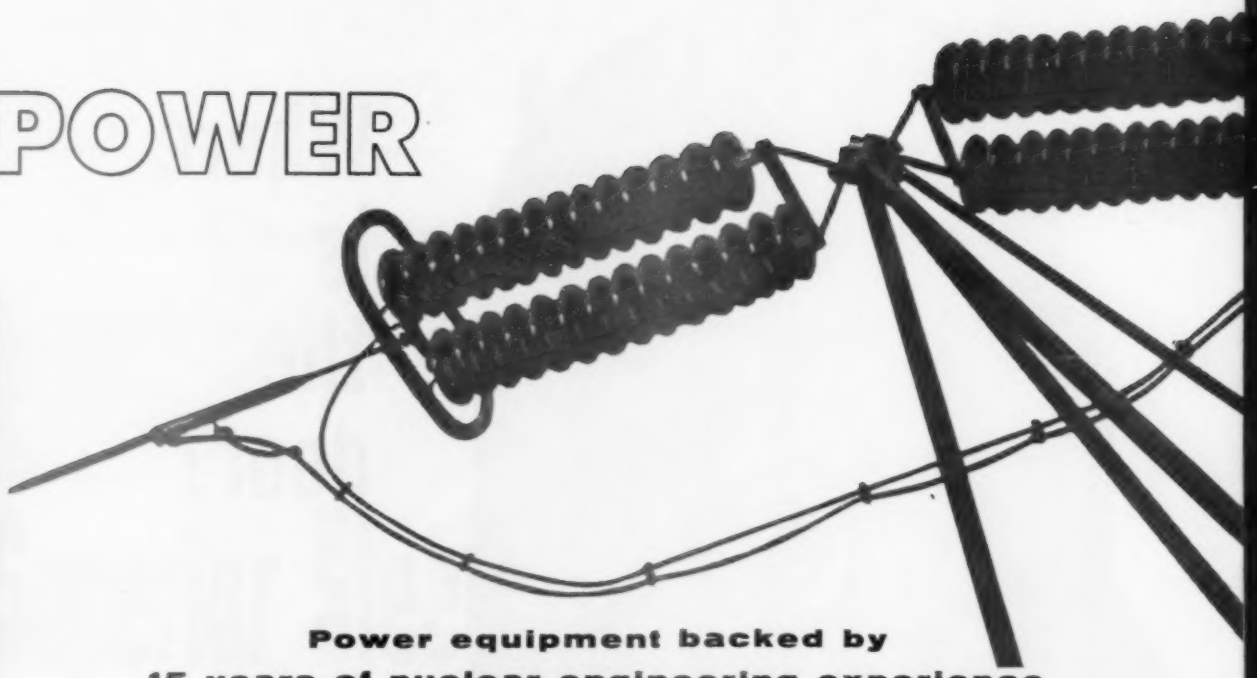
Reactors

Steam Turbine Generators

A-C ALLIS-CHALMERS

A-5790

# POWER



## Power equipment backed by 15 years of nuclear engineering experience

ALLIS-CHALMERS development of nuclear reactors and allied equipment is a logical outgrowth of 75 years of building basic power equipment.

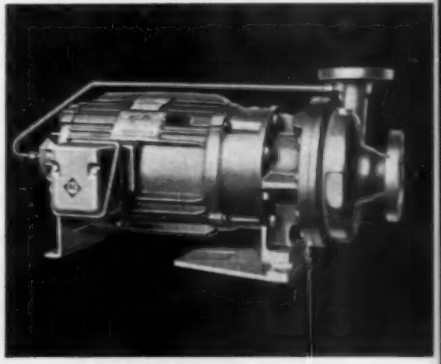
With nuclear experience dating back to the Manhattan Project, facilities, engineering, and production skills are being utilized to produce nuclear power equipment with the same high standards that identify A-C steam turbine generators, condensers, pumps, water conditioning equipment, control, switchgear, breakers, and transformers.

Allis-Chalmers is now engaged in the design and will construct a 66,000-kilowatt nuclear power plant* for the Northern States Power Company in cooperation with ten other electric companies.

**Equipment and engineering for all nuclear power plant needs . . .**

**Condensers**

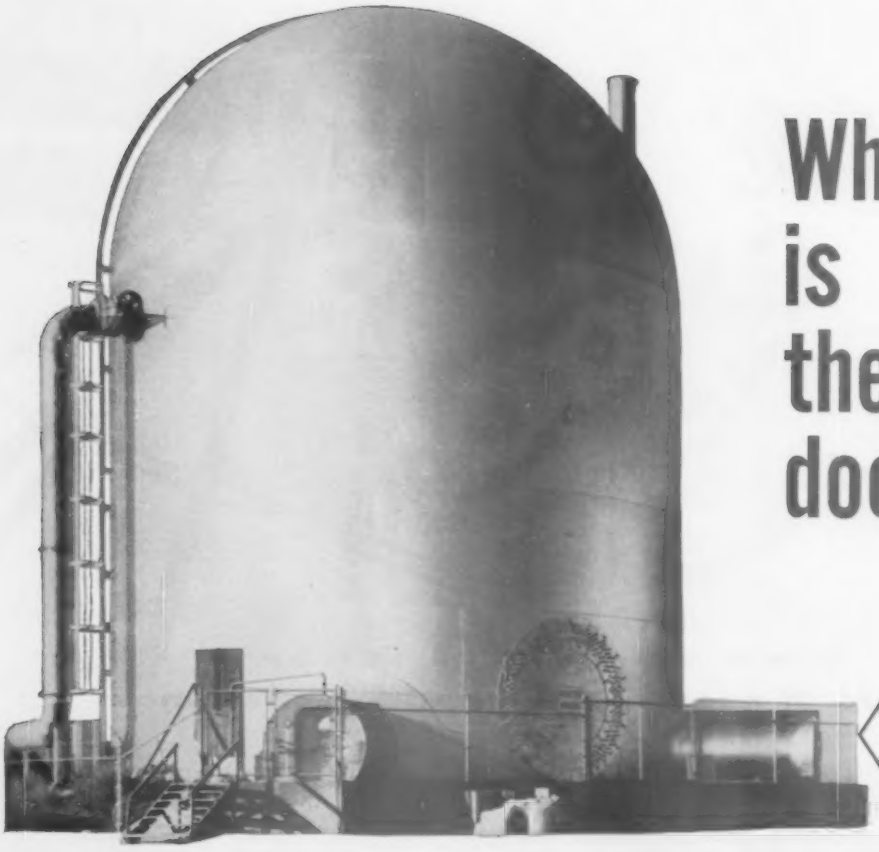
**Control and Switchgear**



**Nuclear Pumps**

# ALLIS-CHALMERS

*A model of a nuclear power plant using a Controlled Recirculation Boiling Reactor with nuclear superheater will be featured in the Allis-Chalmers exhibit in the United States Exhibition Area, Geneva Atoms for Peace Exhibition.



# Where is the door?

*These two tubular entrances are the Pratt Air Locks in the Vallecitos Boiling Water Reactor at the General Electric Vallecitos Atomic Laboratory at Pleasanton, California.*

## The Henry Pratt Personnel Air Lock

**provides easy passage in and out of containment vessels in full compliance with the AEC code for reactor construction.**

While the Air Locks are designed and built specifically for each atomic power plant, they all include some very desirable Pratt developments.

An interlocking feature that keeps one door shut while the other is open is typical of the many simple operating principles that add up to a high safety factor. Any arrangements of automatic and manual controls can be incorporated.

The locks can be built to withstand any practical pressure with compression or pneumatic door seals . . . size is no problem—locks are now being built that will accommodate trucks.

**Air Locks already installed** . . . Two locks in the Boiling Water Reactor of General Electric's Vallecitos Atomic Laboratory, Pleasanton, California . . . Two locks in the M.I.T. Research Reactor.

**Air Locks now being built**. . . Three locks for the C.N.R.N. Reactor, Ispra, Italy . . . One lock for the Enrico Fermi Atomic Power Plant of the Detroit Edison Co., Laguna Beach, Michigan . . . Two locks for the 30 MW Test Reactor at the General Electric Vallecitos Atomic Laboratory, Pleasanton, California.

**Manufacturers of**

Personnel Air Locks
Rubber Seat Butterfly Valves
Turbine-Condenser Expansion Joints
Paper Mill and Converting Equipment
Specialized Steel Fabrication

HENRY PRATT

*One of the two Pratt Air Locks now in use at the M.I.T. Research Reactor.*

Henry Pratt Company, 2222 S. Halsted St., Chicago 8, Ill. Representatives in principal cities

special experience

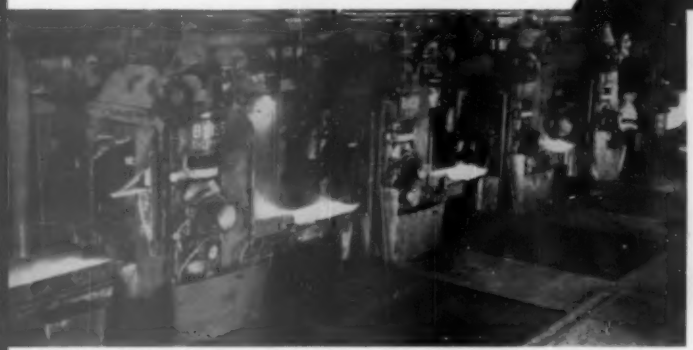
specially equipped

to process the metals required

today in atomic energy applications

# Superior Steel

Boron Stainless Steel • Zirconium • and its alloys



▲ Highest quality Boron Stainless and Zirconium strip are rolled on Superior's Continuous Hot Mill.

Vital to light-gauge Zirconium strip production are this modern Vacuum Annealing Furnace (top) and related pumping equipment.

Complete facilities for degreasing metals are an important element in Superior's processing leadership. ▼

A pioneer in the development of Boron Stainless Steel with experience in the rolling and processing of zirconium and its alloys, *Superior Steel* has the technical background, production experience and the special equipment necessary to meet the exacting requirements for atomic energy applications. Write for our Research Bulletin 57-N.

**Superior Steel**

DIVISION OF

COPPERWELD STEEL COMPANY

CARNEGIE, PENNSYLVANIA

For Export: Copperweld Steel International Company, New York

## N.S. Savannah Progress Report:

Checking the concentricity of the outside and inside diameters and the machined surface on top of giant forging for N.S. Savannah reactor vessel.

# B&W Completes 22-Ton Bolting Flange For World's First Nuclear Powered Merchant Ship

**This huge bolting flange is part of the vital seal for the reactor vessel of the world's first nuclear powered merchant ship—the N.S. Savannah. Recently completed at B&W's Barberton Shops, the flange is a forged ring weighing approximately 44,500 pounds—over 10 ft in diameter and 2½ ft thick. Specifications called for stainless steel cladding and, despite its great size and weight, *precision tolerances of .005 in. linear and 0° - 30' angular.* It contains tapped holes into which closure head studs are installed for retention of a formed hemispherical 9-ft diameter head. The completed reactor vessel, of which this precision-built flange is an important part, will stand nearly 27 ft high, and is designed to operate at 2000 psig at a temperature of 650 F.**

**The experience, skills and facilities developed to produce heavy equipment for the steam generating, petroleum, pulp and paper and process industries have earned B&W a position of leadership as manufacturers of heavy nuclear components. The precise tolerances required present new and unusual manufacturing problems—but problems which are being successfully solved by B&W's skilled engineers and craftsmen.**

**For nuclear components—or complete nuclear power systems—consult The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, N. Y.**

BABCOCK & WILCOX

BOILER DIVISION

NC-101

# Around the world and still expanding

## *Norton products for nuclear progress*

In the growing Nuclear Industry — one of the most important factors in the future of all mankind — the constant interest and steadily increasing participation of Norton has resulted in important refractory product developments, including:

- *Ceramic fuel units of uranium oxide — alone or in combination with thorium oxide — made to exact specifications.*
- *Metallurgical refractories for processing and reprocessing nuclear fuel materials and other unusual alloys and metals.*
- *NORBIDE* boron carbide for shielding and control rods. This chemically and thermally stable material is lightweight, and absorbs neutrons without becoming radioactive.*
- *ALUNDUM* aluminum oxide, MAGNORITE* magnesium oxide, CRYSTOLON* silicon carbide and other high-purity oxides, borides, carbides and nitrides, as source materials or structural components.*
- *ROKIDE* ceramic spray coatings of aluminum oxide, zirconium oxide, zirconium silicate; also, silicon carbide coating for graphite. Resistance to corrosion and heat are the typical characteristics enabling these coatings to upgrade materials for reactor construction.*

Stable, high-melting refractories for a variety of other industrial applications are supplied by the international, constantly growing organization of Norton plants and branch offices. For further information see your Norton Representative or write NORTON COMPANY, 657 New Bond Street, Worcester 6, Mass.

*Trade-Marks Reg. U. S. Pat. Off. and Foreign Countries

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REFRACTORIES
Engineered... ℞ ...Prescribed

Making better products . . . to make your products better

NORTON PRODUCTS Abrasives • Grinding Wheels • Grinding Machines • Refractories • Electrochemicals — BEBB-MANNING DIVISION Coated Abrasives • Sharpening Stones • Pressure-Sensitive Tapes

# ROSS IS READY

## HEAT EXCHANGERS FOR NUCLEAR SYSTEMS

During the past four decades, as new industries have risen with new needs for specialized heat exchange equipment, Ross has always been eager and ready to meet their requirements. New problems are continually welcomed at Ross.

It is not surprising therefore, that when the first atomic reactor became a reality, Ross was ready to enter the nuclear energy field. Today it has the imagination, the skill to work with specialized materials, and the ability to meet rigid specifications in the development of heat exchangers for nuclear power systems.

An engineering concern from top to bottom, Ross is able to call on its own huge store of accumulated experience, plus the vast resources of American-Standard* through its Atomic Energy Division. With the most modern research, manufacturing, and testing facilities at their disposal, Ross engineers are alert to nuclear requirements and ready to develop engineered solutions to the many challenging heat exchange problems.

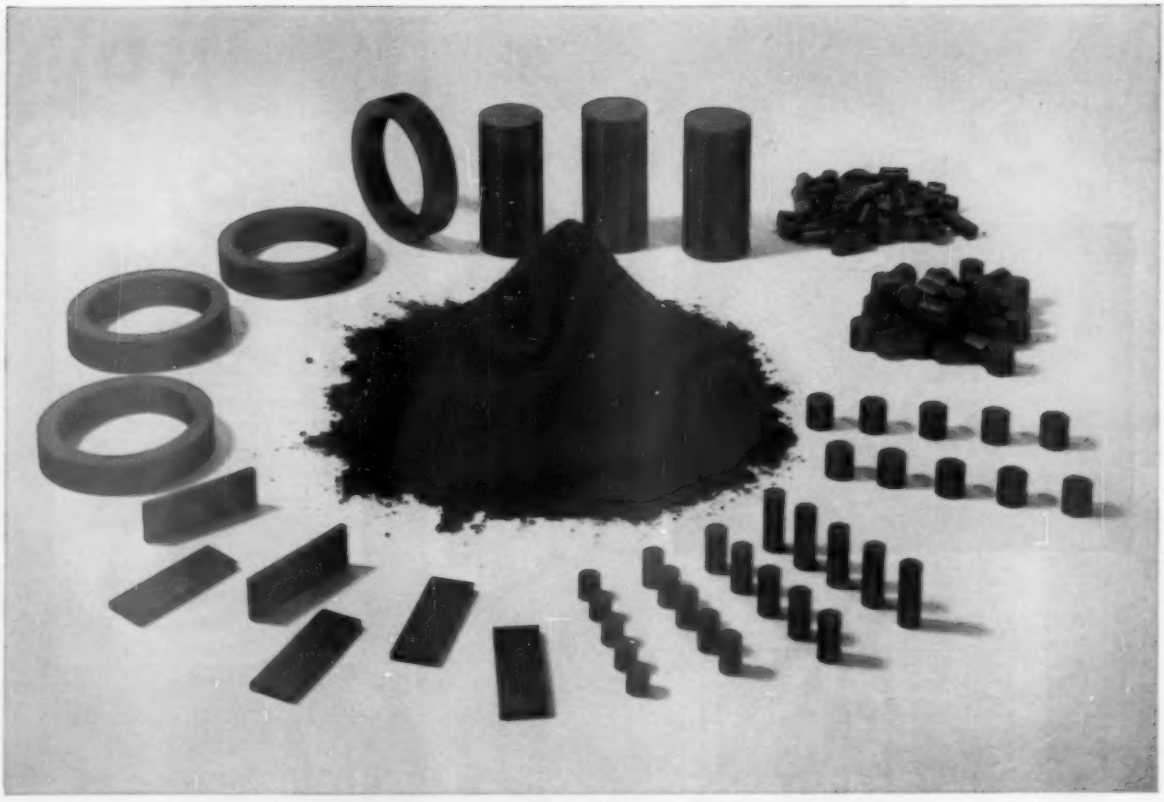
Why not put Ross to work for you? Your inquiries are invited. American-Standard, Ross Heat Exchanger Division, Buffalo 5, N. Y. In Canada: American-Standard Products (Canada) Limited, Station D, Toronto, Ont.

*American-Standard and Standard ® are trademarks of American Radiator & Standard Sanitary Corporation.

American-Standard Products

AMERICAN-Standard

ROSS HEAT EXCHANGER DIVISION



# NUMEC uranium oxides and compounds meet every nuclear fuel specification

One of the many ways in which NUMEC serves the nuclear energy industry is in the production of high purity oxides and compounds, such as $UO_2$, $UO_3$, $U_3O_8$, ammonium diuranate, uranyl sulfate, and uranyl fluoride, in any enrichment. Because of our advanced facilities and thoroughly experienced personnel, we can produce these materials promptly, to meet any current specifications.

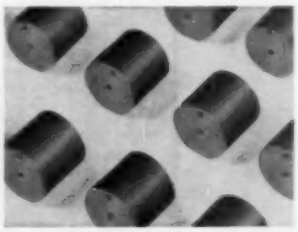
The oxides can be supplied as high-fired or sinterable powders or as finished high-density pellets, plates, rings and cylinders, held to extremely close dimensional tolerances.

NUMEC also produces uranium and thorium alloys; metallic and ceramic dispersions; control and moderating materials; special equipment such as cathodic vacuum etchers and vacuum furnaces; and many other items.

Services available to the industry include unirradiated scrap recovery; wet analytical chemistry; emission and X-ray fluorescence and diffraction spectroscopy; uranium isotopic assays; metallography; tensile, fatigue, impact, hardness and burst testing; helium mass spectrometer leak detection; high-temperature, high-pressure corrosion testing; arc and induction melting; brazing and inert gas welding.

In short, NUMEC has fully integrated chemical, ceramic, metallurgical and scrap recovery production and testing facilities—manned by personnel distinguished by their important contributions to reactor design and fabrication as well as to materials development and production.

We invite your inquiries.



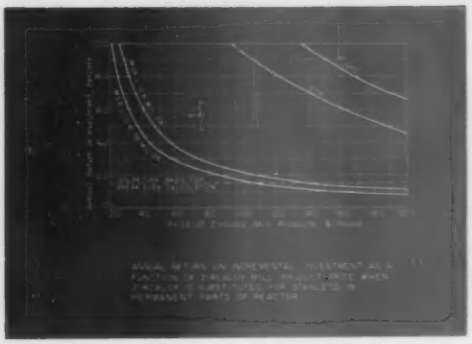
The $UO_2$ pellets shown at the right illustrate some of the difficult fabrication problems NUMEC has solved. As sintered, density is 94%; diameter .356" ± .002"; height .356" ± .010". Each pellet contains two thermocouple holes .032" in diameter. The edge of the outer hole is .030" from the periphery of the pellet.

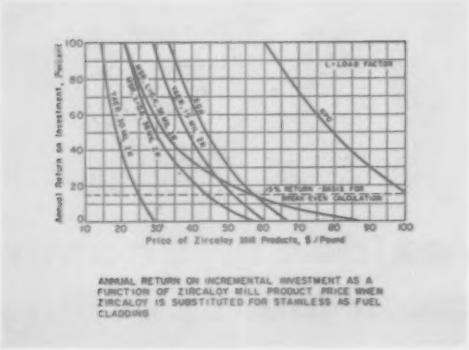
NUMEC

**Nuclear Materials and Equipment Corporation**

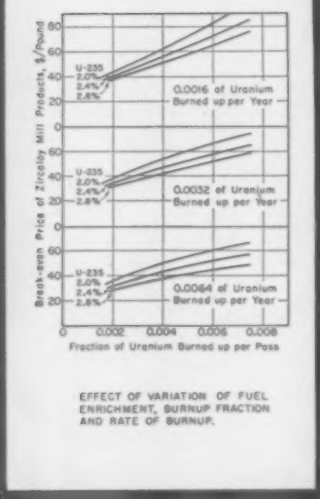
**Apollo, Pennsylvania**

**Telephone: GRover 2-8411** **Cable "NUMEC"**

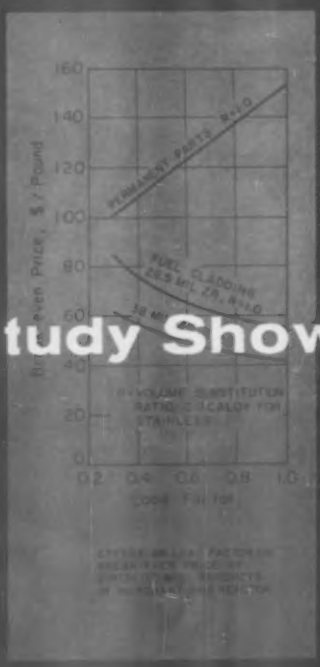



Annual Return on Investment, Percent
Price of Zircaloy Mill Products, $/Pound
L=LOAD FACTOR
25% RETURN BASIS FOR BREAK-EVEN CALCULATION

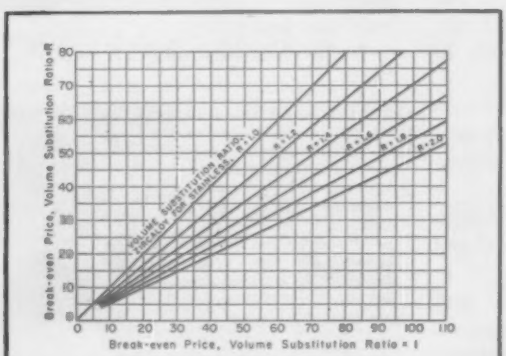
ANNUAL RETURN ON INCREMENTAL INVESTMENT AS A FUNCTION OF ZIRCALOY MILL PRODUCT PRICE WHEN ZIRCALOY IS SUBSTITUTED FOR STAINLESS AS FUEL CLADDING


Break-even Price of Zircaloy Mill Products, $/Pound
U-235
2.0%
2.4%
2.8%
0.0016 of Uranium Burned up per Year
0.0032 of Uranium Burned up per Year
0.0064 of Uranium Burned up per Year
Fraction of Uranium Burned up per Pass

EFFECT OF VARIATION OF FUEL ENRICHMENT, BURNUP FRACTION AND RATE OF BURNUP.

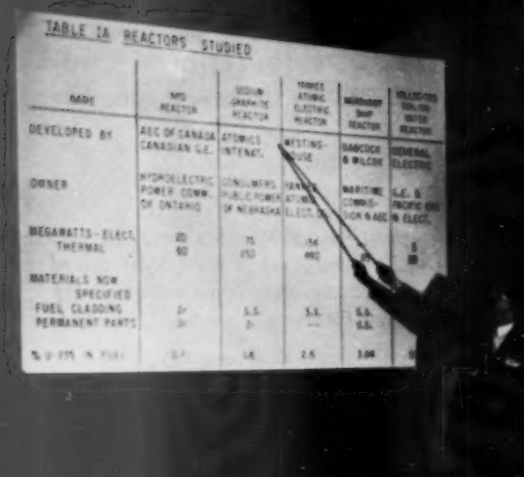



# Columbia-National Study Shows...

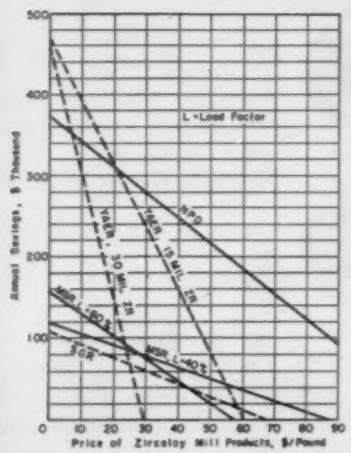



EFFECT OF ZIRCALOY TO STAINLESS SUBSTITUTION RATIO ON BREAK-EVEN PRICE OF ZIRCALOY

NEW METALS FOR INDUSTRY




Dr. Manson Benedict, head of the Nuclear Engineering Department at M.I.T., points to data on the reactors studied, at a recent symposium held to present the results to industry representatives.




ANNUAL SAVINGS IN DIRECT OPERATING COSTS FROM THE SUBSTITUTION OF ZIRCALOY FOR STAINLESS STEEL IN FUEL CLADDING

# how to Save Money with ZIRCONIUM

The relative values of zirconium and stainless steel in five power-producing nuclear reactors have been studied for Columbia-National by Dr. Manson Benedict.

This study shows that the low neutron absorption of zirconium (or Zircaloy) can often contribute important savings through the use of uranium of lower enrichment, through reduction in the critical mass of uranium, or through some combination of these features. The effects of changes in the principal design variables have been studied to make the results applicable to a wide range of reactors.

A summary of the results of this study will be sent to those requesting it on business letterheads.

## Columbia-National Corporation

*Jointly owned by National Research Corporation and Columbia-Southern Chemical Corporation*

**Dept. R5-F—70 Memorial Drive, Cambridge 42, Mass.**

## SPECIAL PRE-PUBLICATION ANNOUNCEMENT

**The United Nations announces the publication in English of the complete PROCEEDINGS OF THE SECOND UNITED NATIONS INTERNATIONAL CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY (Geneva, September 1st to 13th, 1958).**

More than 2,200 papers (double the number presented at the 1955 Conference) covering all aspects of the Peaceful Uses of Atomic Energy will be presented at the Conference in which approximately 70 countries will participate and discuss their latest achievements, both experimental and practical. The main subjects of the Conference are listed below:

- Basic physics
- Basic chemistry
- Biology and medicine
- Use of nuclear energy for purposes other than generation of electricity
- Thermonuclear developments
- Possibility of controlled fusion
- Raw materials
- Production of nuclear materials
- Research and power reactors
- Reactor technology
- Production and uses of isotopes
- Training in nuclear sciences

THE ENGLISH EDITION is expected to consist of 34 volumes (approximately 500 pages each), which will become available beginning December, 1958; publication is expected to be completed by June, 1959.

A SPECIAL PRE-PUBLICATION PRICE of $435 (or equivalent in other currencies) for the complete set is now available, and orders will be accepted on this basis until November 30, 1958. The regular price for the full set will approximate $510.

Abridged editions in French and Spanish are planned for simultaneous publication. They will consist mainly of the papers presented orally at the Conference (approximately 500), the papers submitted in the language of the edition, and a selection of other papers. These editions are expected to be in 15 volumes, and a pre-publication price is available (up to November 30, 1958) of $190 or equivalent in other currencies.

*For further details consult your local bookstore or*

**UNITED NATIONS, NEW YORK**

*Brochures giving further details available on request*

# IN SRE... Zallea expansion joints absorb thermal expansion of reactor core tank and outer tank

The very nature of the Sodium Reactor Experiment, conducted by Atomics International for the AEC, and the method of handling the liquid sodium reactor coolant demand reliability in expansion joints. Because of the operation there can be no compromise in design or quality.

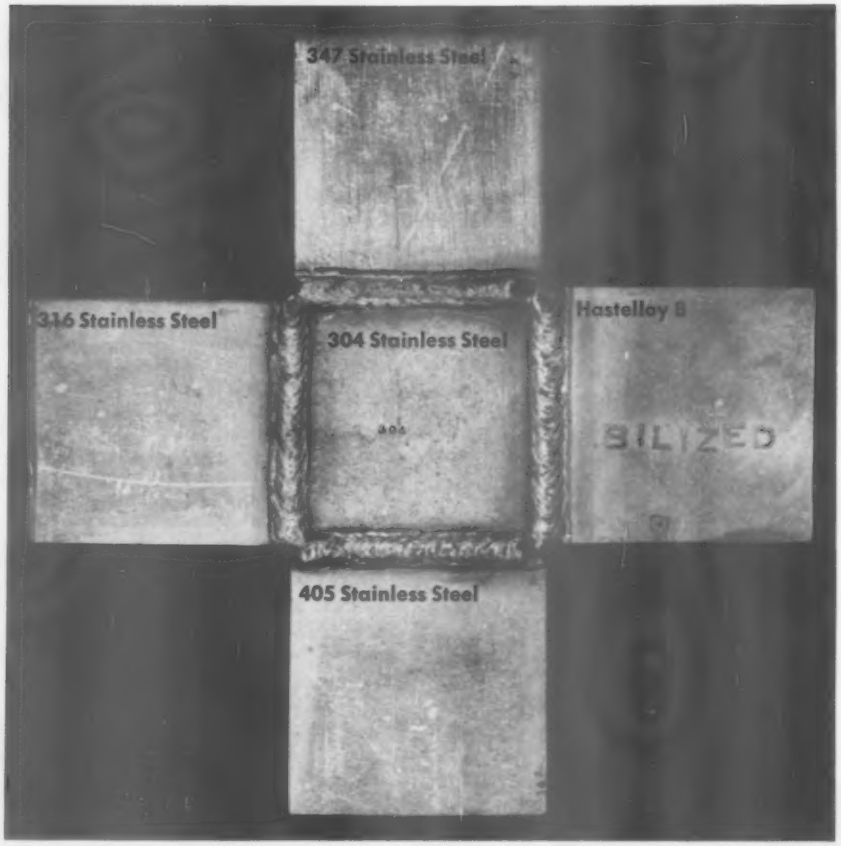
The high temperature SRE uses Zallea Expansion Joints where thermal expansion must be absorbed and where a gas seal must be maintained. An 11-ft. diameter Zallea Expansion Joint at the top of the outer tank absorbs the expansion that results from the temperature increase in these components as the reactor comes up to operating temperature, 960°F. In addition, the expansion joints form a seal for the helium gas and sodium vapor above the sodium pool at the top of the reactor as well as for the helium gas within the outer tank.

In the sodium coolant piping circuit gas seals are effected by means of Zallea Expansion Joints in the region where the pipes leave the reactor cavity and enter the pipe galleries.

Zallea has worked with almost every major engineering and manufacturing firm engaged in atomic, nuclear and missile work—and has provided the large majority of expansion joints for such projects. As a result, we have accumulated a store of expansion joint engineering data and manufacturing skills that cannot be equalled. Whenever expansion is involved in piping systems, reactors, tanks—whatever the application—let our engineers work with you. We already have the answer to many of the difficulties you will encounter. And we welcome the chance of tackling your problem.

*Zallea*
*expansion joints*

ZALLEA BROTHERS, Wilmington 99, Del. • World's largest manufacturer of expansion joints




**With versatile Inco-Rod "A", weldors produce strong, ductile joints in a wide variety of dissimilar alloys. In *this* test specimen, sound welds were produced between four different alloys and the Type 304 Stainless Steel plate at center.**

# Versatility ...the big plus in Inco-Rod "A" that permits welding joints between most dissimilar alloys

Nuclear engineering subjects equipment to an unusual variety of demands. Different parts of the same unit may be called on to resist radiation ... heat ... corrosion ... or other forms of attack.

The job is likely to call for the use of several alloys — and many welds between dissimilar alloys.

Now an electrode has been developed to handle most such welding jobs. It is the new Inco-Rod "A"* electrode.

The 4-to-1 test specimen above demonstrates some of the varieties of dissimilar alloys you can weld with it. In this specimen, type 304 Stainless Steel is joined to Types 405, 316 and 347...and to Hastelloy B. There's proof of versatility!

Fact is . . . better than 90% of most dissimilar alloy combinations . . . involving ferritic and austenitic stainless steels, low alloy steels, mild steels, high nickel alloys and other alloys can be handled with this *one* electrode.

With Inco-Rod "A", weldors can produce strong, sound, ductile joints, without need for special equipment or training.

Welds are strong and ductile . . . of X-ray quality. Corrosion resistance in many media usually equals or exceeds that of the base metal. And operability is excellent in any position . . . spray type arc . . . easy slag removal.

**Do you need to join dissimilar metals?**

Ask for our useful folder on Inco-Rod "A". It covers test data on 23 different alloy combinations. For help on a current welding problem, contact Inco's Technical Service Section.

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**The INTERNATIONAL NICKEL COMPANY, Inc.**
67 Wall Street New York 5, N. Y.

INCO TRADE MARK **Welding Products**
electrodes, wires, fluxes

**AVAILABLE IN:**

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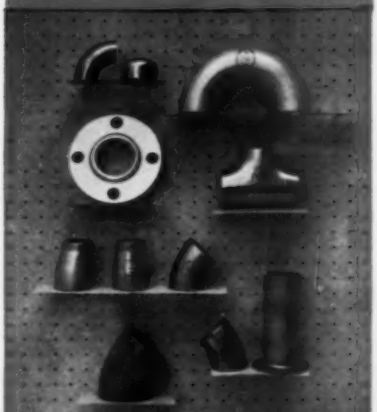
|---|---|
| Stainless Steels | Silicon Bronze |
| Aluminum Alloys | Red Brass |
| Nickel | Admiralty Metal |
| Monel | Titanium |
| Inconel | Zirconium |
| Hastelloy B&C | Zircaloy |
| Copper | |

. . . and other non-ferrous metals and alloys



# NOW...individual packaging protects each TUBE-TURN alloy welding fitting and flange

Tube Turns is now safeguarding the top quality of its stainless steel, aluminum and other alloy products with individual packaging. All of these fittings in sizes through 12", and flanges through 8", are now wrapped in kraft paper and individually packaged in a rugged container, built to standards established by extensive testing. Hence, from point of rigid inspection to job site, *each* fitting is *protected* against damage.

Here is new *convenience*, too. Your fittings are easier to store. And each container is fully marked with description of fitting or flange, size, schedule, type material and production lot for positive, easy identification in the warehouse or on the job.

Here is another plus value you get when you specify TUBE-TURN* Alloy Fittings and Flanges, and buy them from your nearby Tube Turns' Distributor.

**TUBE TURNS**

DIVISION OF CHEMETRON CORPORATION

Louisville 1, Kentucky

CHEMETRON

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# STRAIGHT TALK TO ENGINEERS

## *from Donald W. Douglas, Jr.*

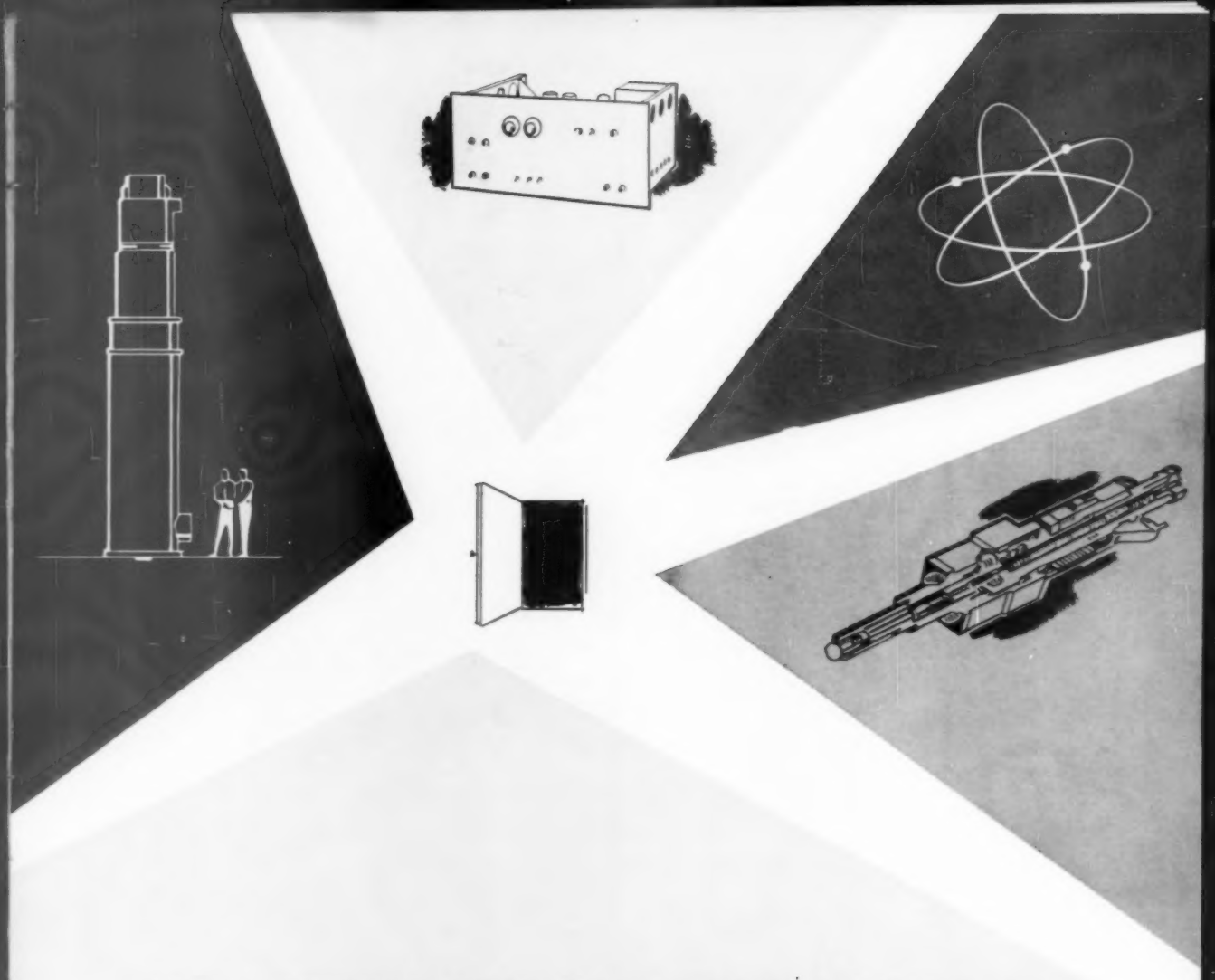
*President, Douglas Aircraft Company*

In your field, as most of you well know, it's easy to be complicated . . . it's hard to be simple. At Douglas, I'm happy to say, we do things the "hard" way. This matter of simplicity is vitally important. We work intensive hours, days and months to achieve it.

Why this extra effort? Well, simple things work easier, last longer, are more easily maintained and are lots more reliable. We are rewarded for our greater engineering effort with a product that performs better for our various customers.

We know that good engineers, working in an atmosphere which stimulates them to do their best, have been largely responsible for our success. If you enjoy solving challenging problems in the simplest manner, we'd like to talk with you about joining us.

Please write to Mr. C. C. LaVene
Douglas Aircraft Company, Box L-620
Santa Monica, California



## TOOLS TO HELP OPEN THE DOOR TO TOMORROW

Translating abstract science into practical progress calls for a host of precision tools and instruments. In the complex field of nucleonics, for example, you'll find the Borg-Warner name on some of the most advanced, most efficient equipment available.

Nuclear pumps, for example, at work in virtually every U.S. reactor; nuclear instrumentation for reactor control, spectrometry, pulse counting and other applications; control rod drive mechanisms.

In each of these products you see the advanced thinking, the skilled engineering and the fine quality that exemplify B-W's guiding principle—"design it better—make it better."

In this way, Borg-Warner serves the exciting world of nucleonics with essential tools to help open the door to tomorrow.

*DESIGN IT BETTER*
*MAKE IT BETTER*

ENGINEERING B-W PRODUCTION

**BORG-WARNER**

200 SOUTH MICHIGAN AVENUE • CHICAGO 4, ILLINOIS

**REACTOR CONTROL INSTRUMENTATION**

**DR Series**—Complete instrumentation for start-up, continuous operation and safety shut-down of nuclear reactors.

**SPECTROMETRY INSTRUMENTATION**

**DZ41—Gamma Ray Spectrometer:** Reduces background as much as 95%. Resolves elements as close as 50 Kev. High stability and reproducibility.

**DZ46—Automatic Gamma Ray Spectrum Recorder:** Single or repetitive scan operation: five selective scan speeds: selective partial spectrum scan. Provisions for 10 mv or 0-1 ma graphic recorder.

Scintillation detectors and well-type counters available as accessory items for spectrometers.

**COUNTING INSTRUMENTATION**

**DM4—Count Rate Meter:** Seven full scale ranges to 200,000 cpm. Responses: 3, 10, 30, seconds. Input sensitivity variable from 0.1 to 5v negative.

**DS8—Precision Binary Scaler:** Precision discriminator 0-100v positive, 0-50v negative; scale-of-64 or scale-of-8 panel selection; self-contained B plus and mechanical register.

**RESEARCH INSTRUMENTATION**

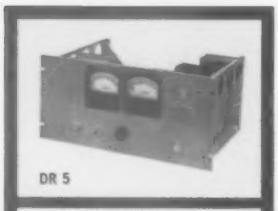
**DZ4—Coincidence Circuit:** Resolving time: FAST Channel, 0.01 microsec. to several microsec.

**DA8—High Gain Amplifier:** Write for Technical Data relative to the new Detectolab non-overload pulse amplifiers. Provides the greatest non-overload factor (4000) of any instrument currently available.

**PRESSURE and TEMPERATURE SENSING SYSTEMS**

For any application involving the sensing of pressure or temperature inquire regarding measurement systems comprised of Vibrotron Digital Transducers. These miniature, electronic, sensing devices apply the basic engineering principle of the vibrating wire to sense changes in pressure, temperature, etc.

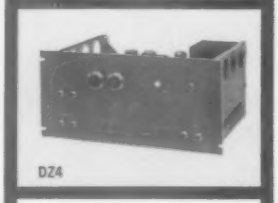
Output in the form of a frequency signal is provided for direct readout as a numerical value. These transducers are suitable for use in areas of radioactivity. Units manufactured from special materials to meet specific requirements may also be obtained.



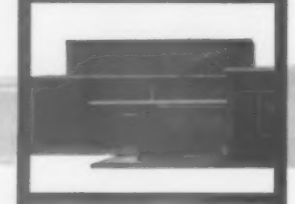
DR 5

DZ46

DM4



DZ4



Sensing Systems

**BJ ELECTRONICS**

**B-W**

**BORG-WARNER**

# For Expanding Nuclear Applications

Internationally-known DETECTOLAB* Products comprise a wide variety of general laboratory instruments to meet virtually every need of the nuclear scientist. New instruments to keep pace with changing requirements and improved versions to enhance the versatility of current models are in advanced developmental stages. Whether standard products or special systems, Detectolab signifies precision and reliability in every field of nuclear endeavor.

DETECTOLAB INSTRUMENTS ARE PRODUCTS OF

## BJ ELECTRONICS

BORG-WARNER CORPORATION

*Reliability you can count upon*

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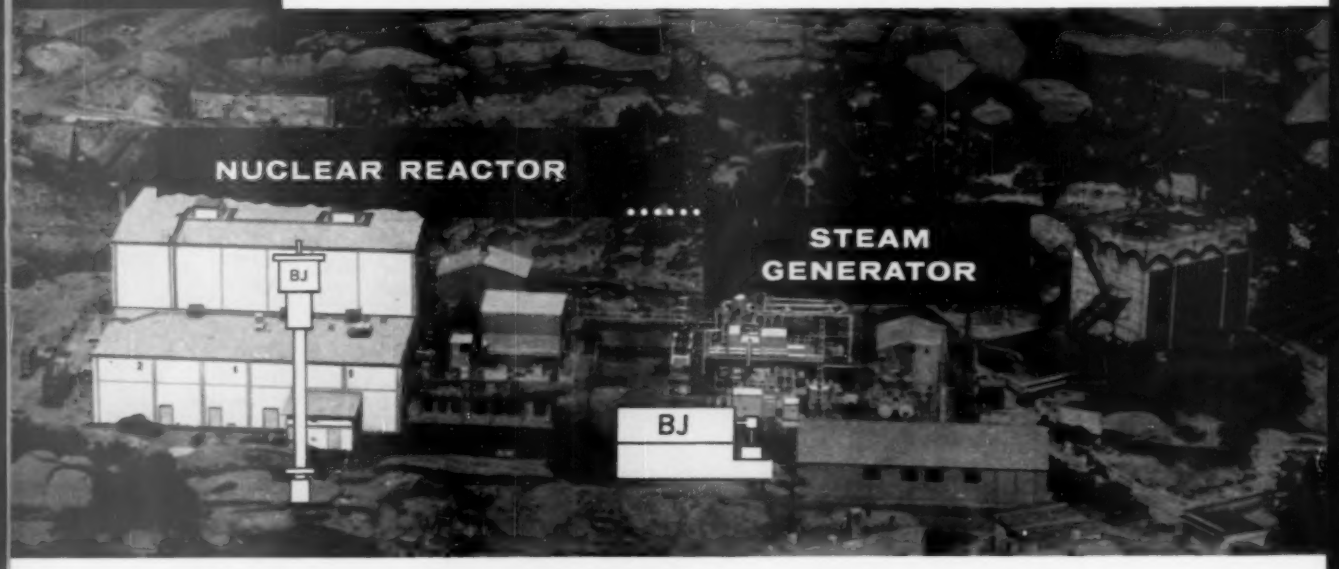
*Borg-Warner Corp. T.M.

# BJ

## Pumps bring both high temperature sodium and water to a steam generator to produce power!




### Santa Susana...the first thermal reactor to produce electric power for a private utility company

This new atomic power plant now in operation near Los Angeles uses BJ pumps to circulate sodium through the nuclear reactor and to transfer reactor heat to the steam generator. The electrical generating plant also uses BJ pumps to deliver feed water to the steam generator. Atomics International, a division of North American Aviation, Inc., designed and built the Sodium Reactor Experiment for the Atomic Energy Commission. The electrical generating plant is designed, built and operated by Southern California Edison Company.

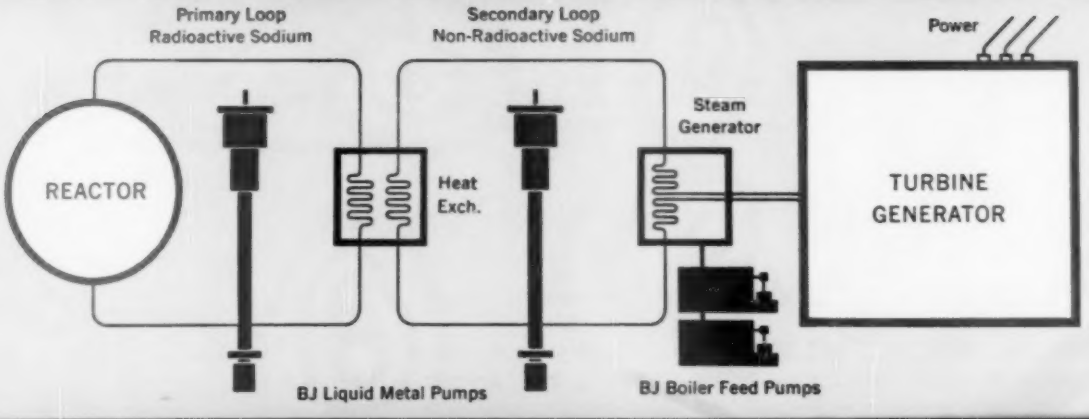
BJ primary liquid sodium pumps take radioactive sodium from the reactors at temperatures up to 960°F. After transfer through a heat exchanger, BJ secondary pumps circulate non-radioactive sodium at temperatures up to 900°F. through a steam generator. At the same point, two BJ 8-stage, SD Multiplex pumps equipped with BJ Type D mechanical seals, deliver feed water to this steam generator. Steam provides the driving force to the turbine generator.

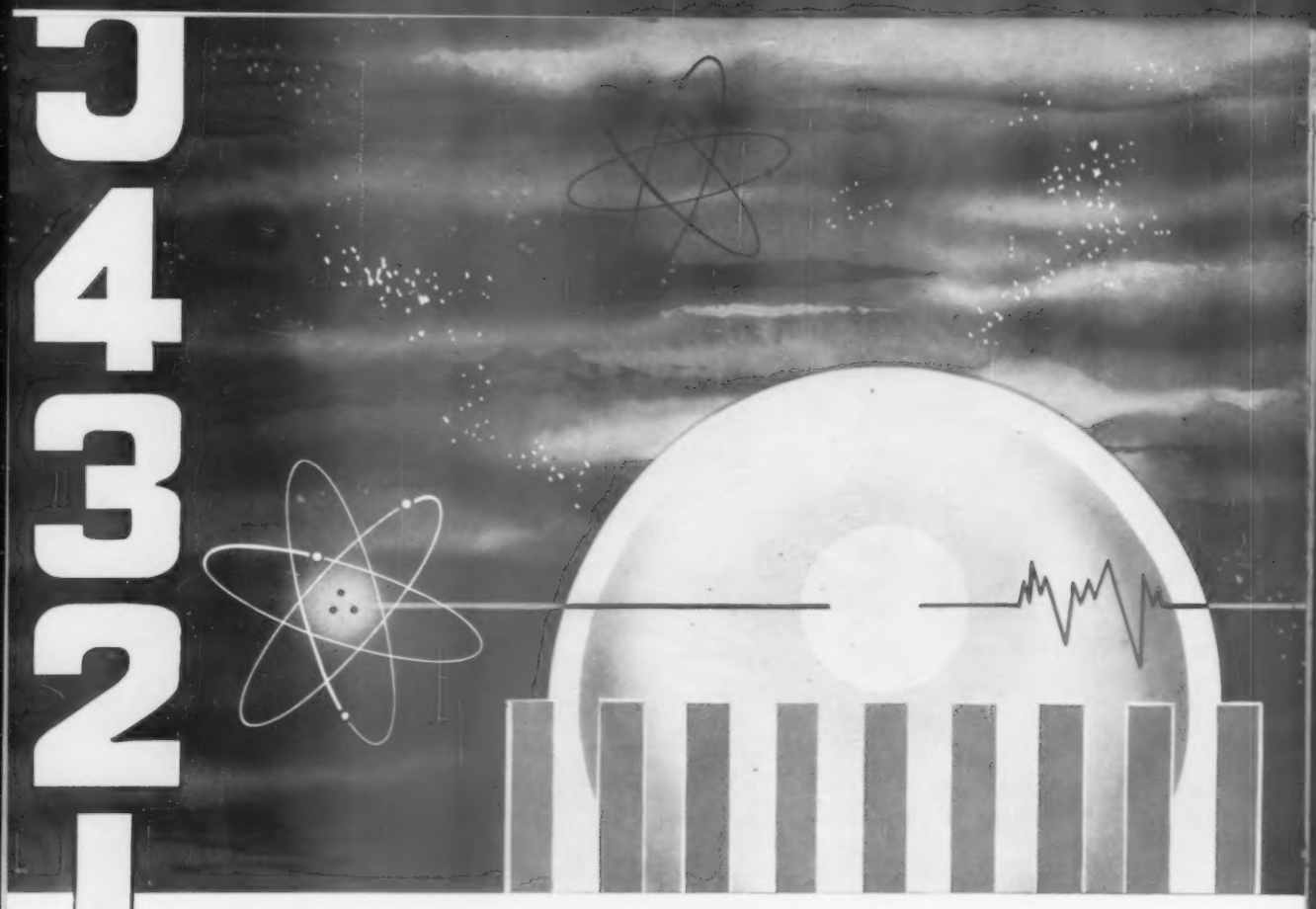
Selection of BJ pumps both for the nuclear and the conventional power system is evidence of Byron Jackson's unique experience and leadership in these dual fields. This experience is available to assist you in finding reliable time-and-money-saving answers to your pumping problems.

**BYRON JACKSON PUMPS**

INCORPORATED

BOX 2017A, TERMINAL ANNEX
LOS ANGELES 54, CALIFORNIA






# Count Down on Experience

Experience is the only answer to the exacting requirements of the rapidly expanding field of nucleonics.

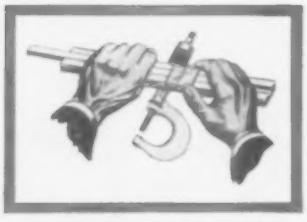
Marvel-Schebler has earned an enviable reputation in the manufacture of precision equipment requiring close tolerances and fine finishes. This experience makes it possible for Marvel-Schebler to offer valuable service to designers and builders of products for the nuclear energy industry.

From planning stage to finished product, Marvel-Schebler's tremendous research, design and manufacturing facilities are at your disposal.

Our research and design engineers are specialists! Every product is the result of exacting production techniques, meticulous quality control and precision testing skills. This means completely reliable, proven equipment that fulfills every critical specification of the Marvel-Schebler customer.

## DESIGNING · ENGINEERING · MANUFACTURING · TESTING

Marvel-Schebler's vast experience in the nuclear energy field includes the design, development and production of control rod drive mechanisms for reactors used in atomic submarines. Marvel-Schebler has been instrumental, also, in development and manufacture of remote handling equipment, hydraulic actuators for guided missiles, fuel pumps and control valves for jet engines, bomb-sight parts, hydraulic depth bomb releases, fuel injection systems, liquid and gas carburetors, aircraft carburetors.



*Call on us to Solve Your Design and Manufacturing Problems!*

Export Sales: Borg-Warner International, 36 South Wabash Avenue, Chicago 3, Illinois

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**BORG-WARNER CORPORATION, DECATUR, ILLINOIS**

MARVEL-SCHEBLER B-W BORG-WARNER

FUSED SEAMS – Exclusive process fuses component parts to and with same materials used as filter media.
CONTROLLED PORE SIZE – from submicronic to 700 microns, depending on media
THIN WALLS – Easier cleaning and decreased differential pressures.
GREAT SURFACE AREA – per unit of volumetric space.
Here's what

# *Purolator can do with*

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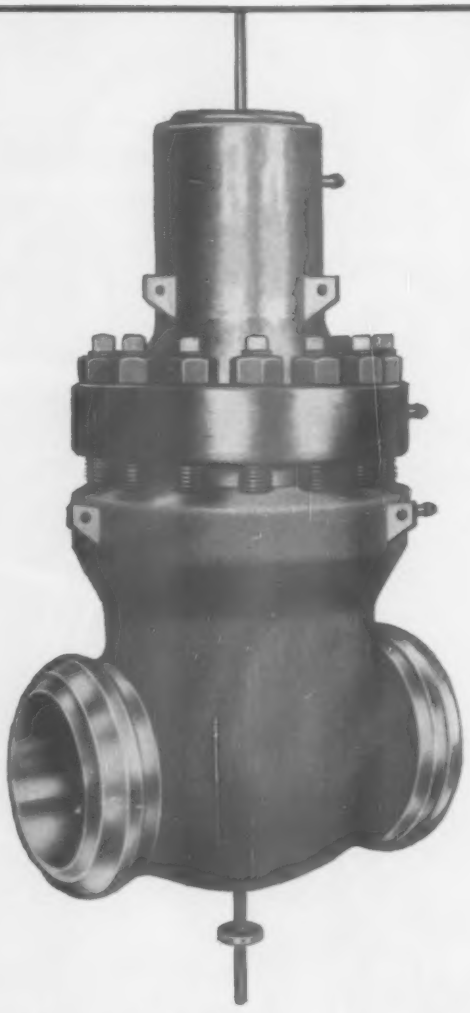

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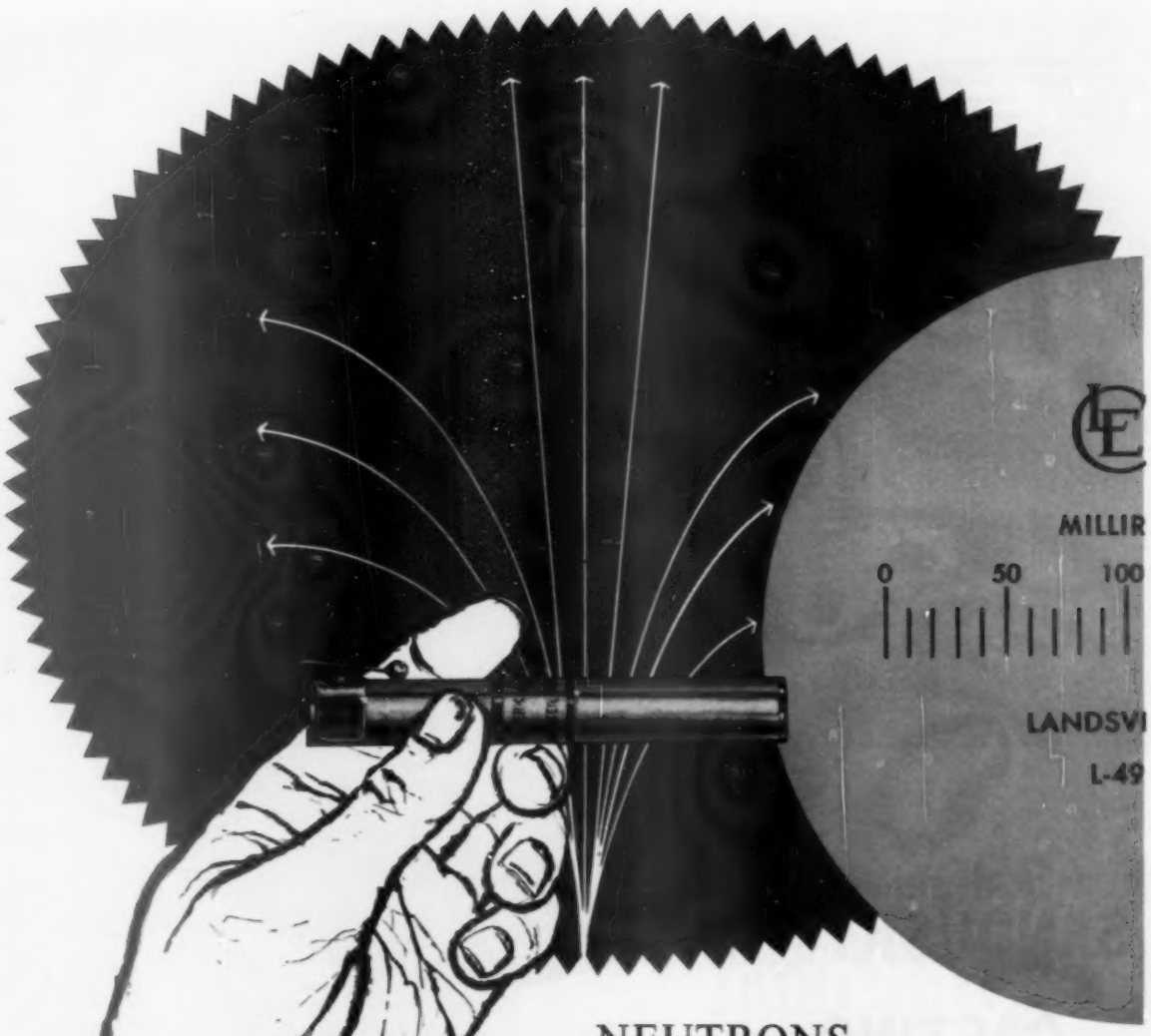


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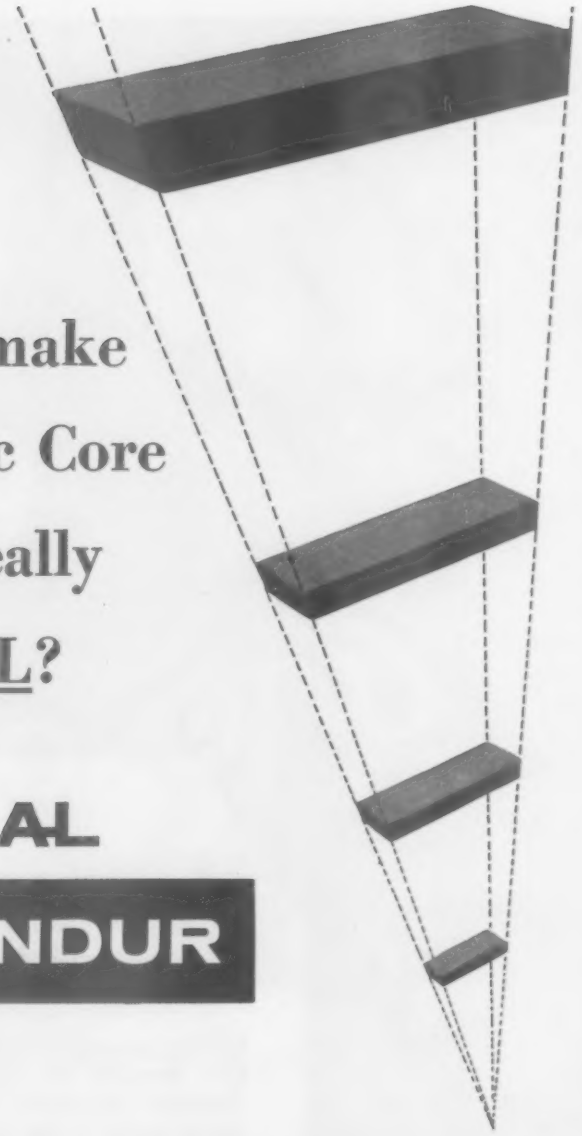

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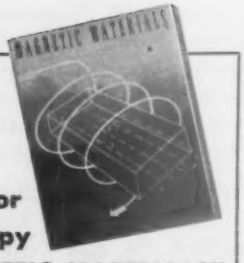


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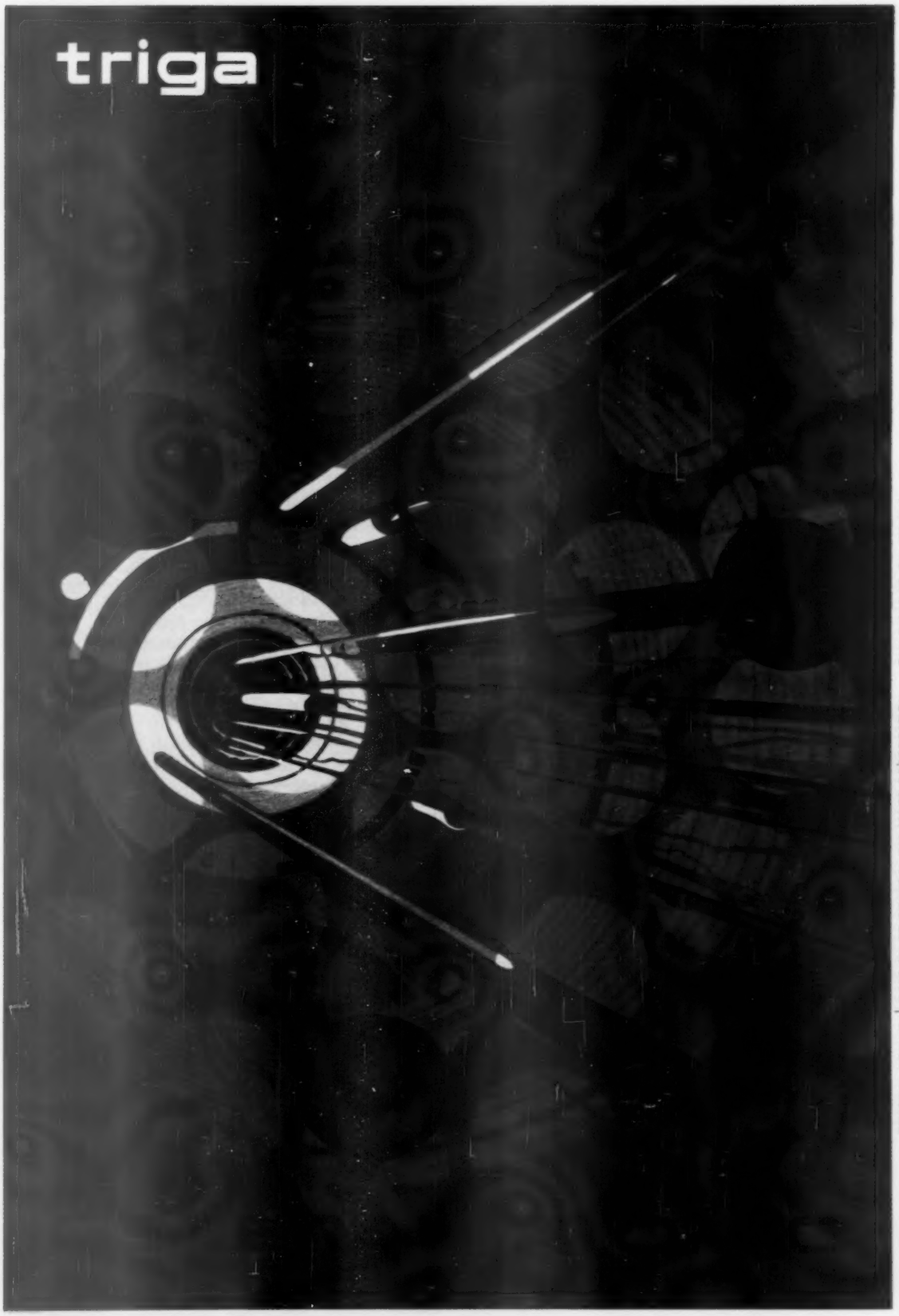
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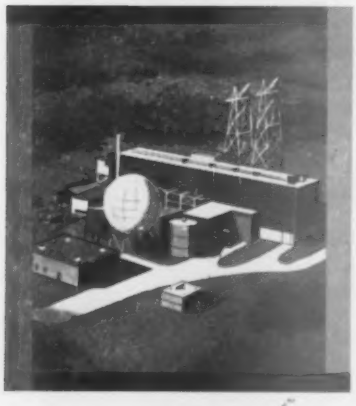

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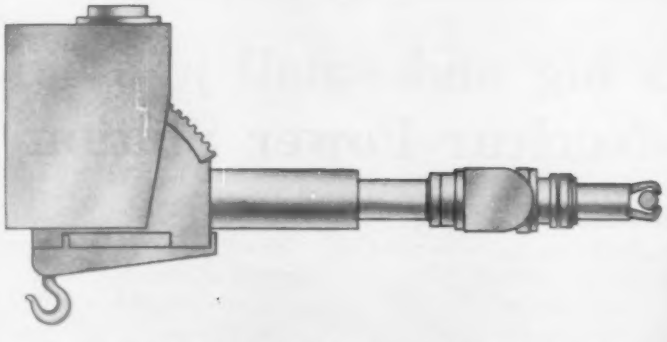

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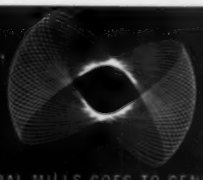

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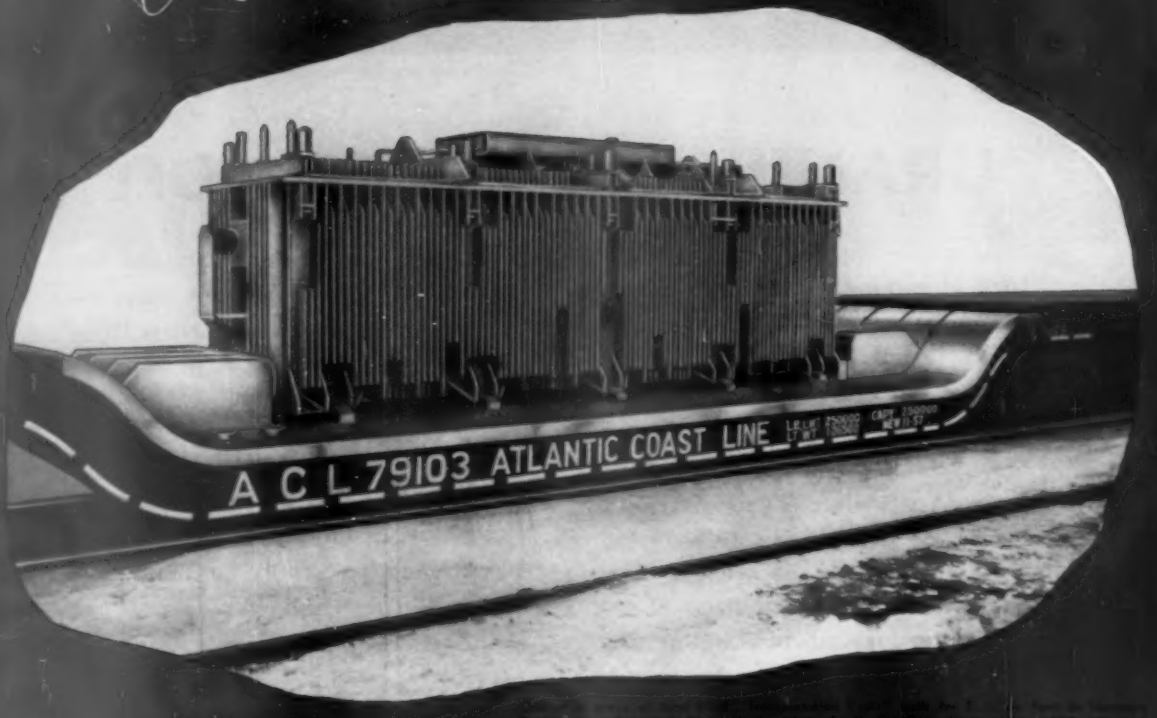


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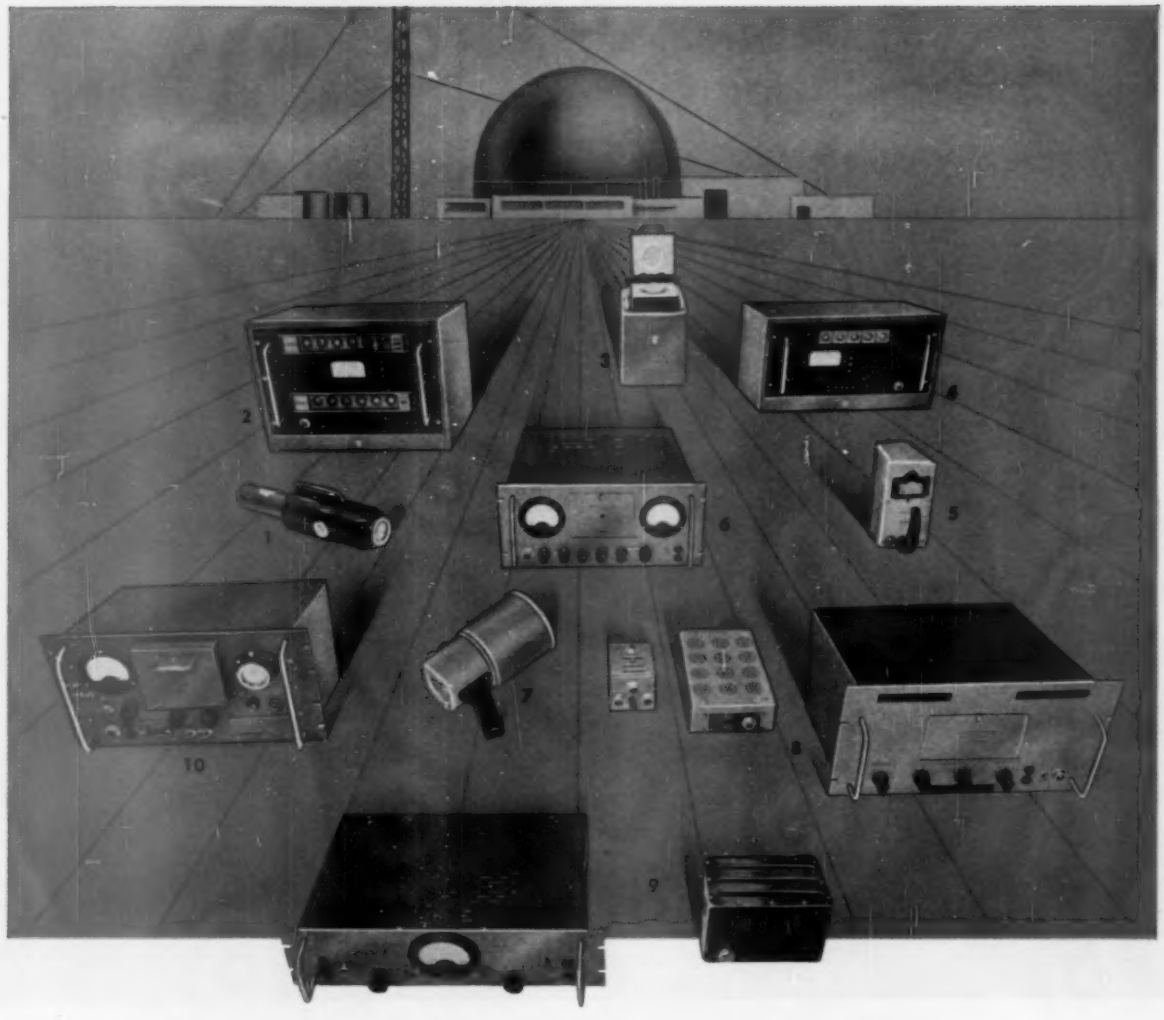

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AUGUST, 1958

*A Guest Editorial*

# Power Breeding As a National Objective

*Ever since it became apparent that nuclear reactors could be used for the production of electricity arguments have raged on the relative importance of breeder reactors. Some have felt that the development of breeders should be a matter of considerable priority. Others have felt that breeders should be worried about in the future when uranium supplies begin to dwindle.*

*Despite these differences of opinion, considerable progress has already been made on breeding in the U. S. In fact, production of the first plutonium in a breeder was announced by the U. S. in 1953.*

*Breeding will undoubtedly be a topic of importance in the forthcoming discussions of the future U. S. nuclear power program. The subject will also be discussed rather fully at Geneva next month.*

*And so, in this issue of NUCLEONICS which is devoted in large part to a report on the U. S. nuclear fuel program, the Editors are pleased to publish the guest editorial below. It is written by the distinguished reactor scientist, Alvin M. Weinberg, who has been one of the most eloquent spokesmen for breeder reactors.—The Editor.*

It is imperative that we clarify our national objectives in power-reactor development. The technological choice of path among the many possible reactor systems depends too sensitively upon the goal we seek to tolerate fuzziness or vacillation in the delineation of our goals.

The primary goal of our civilian nuclear power development generally is assumed to be the demonstration of reactors that will produce power economically in the United States—say, at 8 mills/kwh or less. A secondary aim is to develop systems that make economic sense in other countries—say, at 10–12 mills/kwh. The essential point is that the sole figure of merit that guides the development is mills/kwh.

I wish to argue that to make mills/kwh the sole basis for determining our course is short-sighted and wrong; an equally valid basis for guiding the development is neutron economy. I propose, therefore, that the achievement of practical power breeders be considered as important a goal for our power-reactor enterprise as the achievement of low mills/kwh per se.

First, I shall make two comments on our present motivation in reactor development—one is concerned with the validity of the goal of low mills/kwh, the other with the means by which we seek to achieve low mills/kwh.

As to the validity of the goal of low mills/kwh, I remark first that the incentive to achieve economic nuclear power quickly in the U. S. is not great because we have abundant fossil fuels. Moreover, the computation of mills/kwh depends far too much on arbitrary accounting decisions, or transitory economic conditions, to make this a completely reliable and exclusive basis for deciding on a path of reactor development. Reactor technology is ponderous and time-consuming; it is very dangerous to choose one path and to exclude another simply because the mills/kwh, computed at a certain time in history and

therefore greatly affected by a particular system of accounting or by the current material supply, shows one system to be more economical than the other.

A good example of how such economic considerations can lead one astray is the history of gas cooling in the United States. The early studies of gas cooling, for example one made by the Commonwealth Edison group, were based on high inventory charges. The gas-cooled systems, because of their rather low-material efficiency, therefore suffered by comparison with other systems because of such accounting. More recent studies, based on lower inventory charges, now suggest that gas-cooled systems could lead to favorable costs even in the United States.

I do not, of course, argue that we discard mills/kwh as a figure of merit; I simply state that there are other figures of merit—thermal efficiency, capital cost, neutron economy—the achievement of good performance in any one of which can also determine a technological path. Any estimate of mills/kwh implies a certain weighting for each of these characteristics of a reactor; because there is much arbitrariness in such weighting, I am not convinced that low mills/kwh as computed on the basis of *current* economics is necessarily the whole story. In my view at least one of these other considerations—neutron economy—is as important as the over-all computed mills/kwh.

My other point is concerned with the means for achieving low mills/kwh. If we leave breeders out of consideration, then all of the current reactor types by means of which we hope to achieve low mills/kwh are really very-low-conversion-ratio systems. Even with Pu recycle, they do not claim to burn more than about 3% of the total uranium.

If one is content with burning only a small fraction of the uranium, just so long as the mills/kwh is low, then one must be willing to look at all the schemes that seek to achieve only low mills/kwh. In particular, one should include in the competition the high-thermal-efficiency, highly enriched liquid burners—the U-Bi and the molten salt systems. They, too, burn only a small fraction of all the uranium—perhaps $\frac{1}{100}$ instead of $\frac{1}{30}$ or $\frac{1}{50}$. They make up for a slightly lower conversion ratio by very high thermal efficiency and reduced chemical processing costs. That these systems operate with highly enriched fuel tends to obscure their relation to the systems that operate with slightly enriched fuel. In both cases most of the fertile uranium is thrown away—in the one case in the diffusion-plant tails, in the other case in the waste storage tanks—and therefore the two systems should be viewed as competitors. It is my own impression that in the competition for a reactor that will achieve 8 mills/kwh, the very-high-temperature, fused-salt, low-conversion-ratio burner could become a very significant contender.

My main concern, however, is to restate the case for making the achievement of successful power breeders once more a *primary* objective for U. S. reactor development, equal in status with the achievement of low mills/kwh. The argument is simple and has been stated many times: If nuclear energy is to supply a *major* fraction of our energy, then there is just not enough low-priced uranium to enable us to base our economy on low-burnup systems (I include 20,000 Mwd/ton, i.e., ~3%, as "low" burnup).

Consider a nuclear-power industry in the U. S. equal in magnitude to our present electrical industry—say, $150 \times 10^6$ kw(e)—based on plutonium-recycle, 20,000-Mwd/ton reactors. Assuming a 0.8 load factor and 25% over-all thermal efficiency, this would require 9,000 tons of uranium *per year*, in addition to about 75,000 tons' inventory. This is to be compared with the latest estimate of 150,000 tons of uranium recoverable in the U. S. at $10/pound, perhaps 1,000,000 tons available at $30/pound.

Thus there is hardly any argument against the *ultimate* need for breeding. What then are the arguments against making the achievement of economical power breeders a *primary* objective of the U. S. nuclear power program? I think all of the arguments center around the belief that somehow these devices are too difficult, too cumbersome. To this I say that if we do not pursue power breeders with full vigor, then one decade, and then another, and still another will slip by without our having such systems. We *may* not achieve successful power breeders even if we work hard at them; we *certainly* shall not achieve successful power breeders if we do not work hard at them.

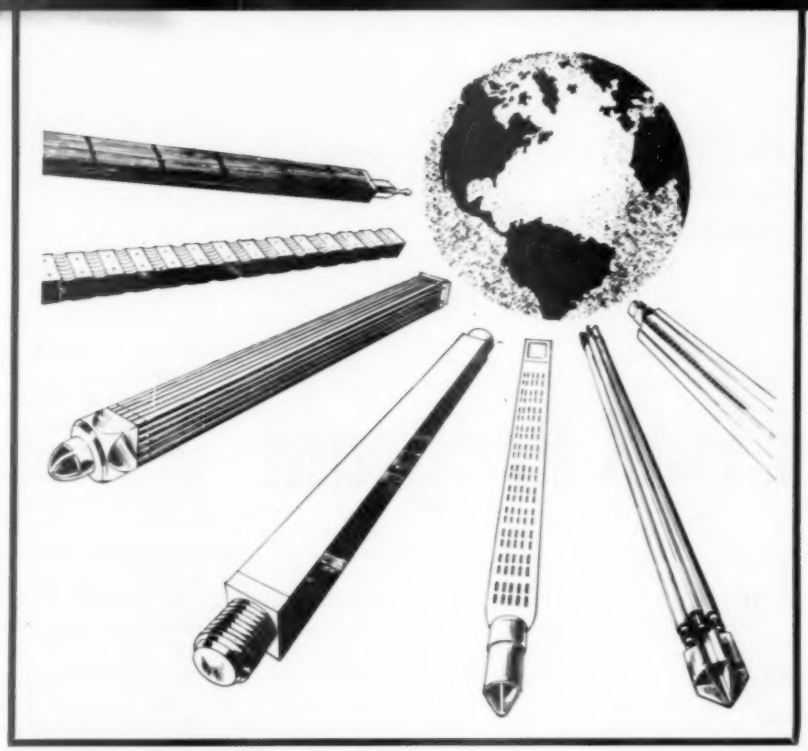
But at least as far as the aqueous-homogeneous thorium breeder is concerned, I am not prepared to concede that the breeders are necessarily more cumbersome than customary nonbreeders. The complications in the homogeneous reactors are in the plumbing and piping systems where all can see rather than, as in the heterogeneous reactors, in the chemical plant or in the metal-fabrication plant whose complications are tucked away out of sight but are nevertheless real.

There is certainly no argument against the view that an economical power breeder that utilizes 35–70% of the raw material is superior to an economical nonbreeder that utilizes only 3% of the raw material. Generally, we think it will take longer to achieve the former than the latter. But in the U. S. we could get along without *any* large-scale nuclear power for a couple of decades. We could use this time to develop the devices that make sense in the long run—the power breeders.

Yet, although we have years of grace, we cannot wait indefinitely. We cannot, for example, wait for controlled thermonuclear energy. The uncertainties in the Sherwood business are far greater than the uncertainties in the breeding business. It is grotesque to compare the feasibility of power breeding with the feasibility of controlled thermonuclear energy, just as it is grotesque to devote, on power breeders, no greater effort than is being spent on thermonuclear energy.

We are trying to develop a technology, not just for the next decade nor even for the next century. We are trying to develop a technology which, if truly successful, can assure mankind a source of energy for thousands of years. I think future generations will judge our efforts to be tragically short-sighted if, in our scramble for low mills/kwh, we not only waste the world's supply of neutrons, but also fail to devote full effort to finding ways of using completely our nuclear fuel.

—Alvin M. Weinberg
*Director, Oak Ridge National Laboratory*



# Fuel for the World's Reactors

## —A Report on U. S. Fuel Technology

On the eve of the 1958 Geneva atoms-for-peace conference, one of the major unknowns continuing to plague students of nuclear power economics is the fuel cycle. Regardless of the particular country involved, areas in question include: enriched versus natural uranium, oxides versus metals, uranium-plutonium cycle versus thorium-uranium cycle, and fuel irradiation times achievable.

Conclusive answers to most of these questions will only come with the successful operation of many of the reactors planned for the coming years. Meanwhile, however, considerable experience has already been amassed that has begun to point directions.

The United States, for example, has accumulated a substantial number of megawatt-days of irradiation of enriched fuels, probably more than any other country in the world. In addition, there is in the U. S. a tremendous program of research and development on all aspects of the fuel cycle.

Based on this background, the U. S. stands ready to offer the world a very usable fuel technology along with assured supplies of enriched uranium. This willingness of the U. S. to assist other nations is probably best exemplified in the proposed agreement with Euratom, which includes a substantial fuel support program.

It is to document this U. S. experience on solid-fuel technology and U. S. offerings of fuel and fuel services that NUCLEONICS has prepared this special report.

Th U Pu

FUEL TECHNOLOGY—U.S.A.

# AEC's Fuel Program

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**GROUND WAS BROKEN June 26 at Argonne National Laboratory for this $17-million 182,000 sq ft Fuel Technology Center. Front wing, at left, will house administrative offices; narrow connecting section behind it is personnel clothes-change and control; the rest—the main body—of building will be devoted to research in all phases of metallurgy of nuclear fuels with major emphasis on plutonium. Design is extremely flexible to permit changes in program emphasis. Two additional wings, not shown in sketch, are already projected: one is an alpha-gamma hot lab for studying irradiated Pu-containing materials, for which a preliminary design has been completed and development of a detailed design authorized; the other is an engineering fuel development and fabrication facility, for which preliminary design is authorized.**

THE FUEL-CYCLE COSTS of a nuclear reactor must include all the expenses of every atom of fuel, from the mining of the uranium and thorium ores to the final disposal of the fission-product wastes. The major components of these fuel costs are: (a) the costs of the fissionable material (interest charges and burnup) and the costs of other ingredients in the fuel elements; (b) the costs of fabricating the materials into fuel elements; (c) the charges for chemical processing of the fuel elements after removal from the reactor, and (d) the costs of waste processing and disposal. There are other fuel-cycle costs, such as inspection, transportation, and losses during processing, but these are relatively minor in importance, and offer little opportunity for significant fuel-cycle cost reduction.

AEC for some time has been actively supporting fuel-cycle development for civilian nuclear power plants. A number of steps are planned to be taken to initiate a major expansion of these activities, extending from materials and process development through the testing of multi-ton batches of developmental fuel elements in full-scale power reactors. To accomplish this, the present Commission program, which includes fissionable and general materials development and testing, chemical processing, and waste disposal work, will probably be expanded by the addition of a supplemental program oriented toward the development, fabrication and testing of a number of fuel-element types suitable for test operation in the various power reactors now in operation or under construction, including those owned by industry as well as those owned by the government.

## AEC Program Goals

The objectives of the over-all program are to develop more efficient fuels for reactors, using $U^{233}$, $U^{235}$, natural U and Pu; to utilize these fuels at elevated temperatures to increased burnup, and to develop fabrication techniques and manufacturing processes that will lower the unit costs of producing fuel elements.

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To achieve these objectives, we hope to initiate a combined fuel-element development program to emphasize three areas of operation:

1. Fundamental engineering research and development on fissionable, fertile, and structural materials that may be efficiently utilized in the fabrication and manufacturing of less expensive fuel assemblies;

2. Design and fabrication of prototype fuel elements having improved resistance to irradiation and longer life at elevated temperatures—such elements to be tested extensively in operating reactors; and

3. Based upon successful performance of these prototype fuel elements, full or partial core loadings will be tested in power reactors under normal operating conditions.

Although AEC is supporting construction of a $17-million Fuel Technology Center at Argonne National Laboratory, as well as additional fuel facilities at the Hanford Engineering Works and at the Los Alamos Scientific Laboratory, it has been concluded that a centralized, government-owned and –operated fuel-element manufacturing facility is neither feasible nor desirable. Fuel-element development represents an integral part of the individual reactor programs of a number of the Commission laboratories and industrial contractors. The plan is to expand and accelerate those developments along the lines that offer greatest promise, both short- and long-range. It is also considered extremely important that various industrial concerns take as large a role as possible in order to continue AEC's policy of encouraging the growth of the nuclear fuel industry. However, in order to focus attention on the specific objectives, the Commission's fuel development will continue to be carried on predominantly as a separate program.

The AEC supplemental program will include a major effort on oxides, carbides and other ceramic or cermet materials containing U, Th and Pu. The work will be aimed primarily toward lower fabrication and materials costs and longer lifetime of fuels suitable for full-scale power reactors. The initial work should result in development of prototype fuel elements that can subsequently be produced in large numbers for tests in full-scale power reactors. Consideration will be given to improved manufacturing techniques and inspection and testing procedures that offer promise of lowering costs in subsequent production of the various fuel elements of major interest. The development of improved, nondestructive test methods offers particular promise.

Obviously this enlarged program will require more test space than is now available in either the Materials Testing Reactor (MTR) or the Engineering Test Reactor (ETR). In accord with announced policy, AEC hopes to secure this additional irradiation space through contracts with the operators of privately-owned test reactors. Fortunately, there are a number of such reactors now built, building or planned. However, more are needed, particularly test reactors of a size suitable for testing full-scale or nearly-full-scale prototype fuel elements. One of the prerequisites for getting on with this part of the program is that AEC have authority to enter into long-term agreements with test reactor operators for provision of this space to meet the development schedule (*see box*).

The expanded program for fuel-cycle development requires that increased effort be devoted to chemical-processing development. The emphasis on oxides, carbides and other ceramics and cermets necessitates expansion of the work already begun on these materials. The work at Oak Ridge National Laboratory on aqueous chemical process development will be accelerated. Increased effort will be placed on volatility work at both Oak Ridge and Argonne. A significant increase should be made in the level of effort being applied to pyrometallurgical process development now under way.

In keeping with the goal of lowered fuel-cycle costs, increased effort will be devoted to developing waste-treatment methods. We need to expand what we are already doing and try to find new ideas that will drastically reduce the present excessive storage costs. We would also hope to include an aggressive program aimed at developing the industrial potential of fission by-products—both the radiation and the heat released.

In addition there are two other areas in which AEC would like to see more work done. Both are aimed at increasing the efficiency of nuclear power plants through attainment of higher temperatures. The comprehensive studies on gas-cooled, graphite-moderated reactors made by Kaiser Engineers together with ACF Industries, and paralleled at ORNL with the assistance of the TVA, were recently reported to the Joint Committee on Atomic Energy. These two groups independently recommended taking a giant step in this field—to design for exit gas temperatures of 1,000° F and above. It is clear that if this could be done it would be a major breakthrough in gas-cooled reactor development. To accomplish this advance will require some really imaginative effort.

The same kind of thinking is required to achieve the other objective: nuclear superheat. Until we can get superheated steam from nuclear power reactors without resorting to chemical-fired superheaters, we will not be able to take full advantage of the progress made during the past 10–20 years in development of high-efficiency fossil fuel systems. The immediate need for this new knowhow is not only in our own domestic program but in the programs of our foreign friends as well.

Among the problems this program is expected to solve are these:

## $27-Million to Irradiate Fuel in Power as Well as Test Units

**Admiral Rickover has urged that AEC make provision in its 1959 program for testing fuel elements in private pressurized water reactors such as Yankee, arguing that this could be done relatively cheaply because the reactor itself would already be in existence.**

**Acting on this idea, AEC has asked $27-million in the '59 appropriation from Congress to support irradiation of fuel elements in privately-owned power reactors (not restricted to pressurized water) as well as test reactors. If Congress approves, AEC will spend ~$15-million in the next few years for space in power reactors, $12-million for test reactor space. Such space contracts would run up to ten years.**

**Also, AEC may be expected again next year to seek money to build one or more test reactors of its own; $35-million for two such facilities was turned down this year by the Bureau of the Budget.**

First and foremost is the development of proven long-lived fuel elements. High burnup of the fuel in a reactor is essential for good economics. For enriched fuel our immediate goal is an *average* of 10,000 Mwd/ton—proven, not postulated.

The program includes development of improved fuel elements containing (a) metallic U, (b) U alloys, and (c) U compounds. The development of the first two areas would be divided into low enrichment and alloy content for thermal reactors, and into medium enrichment and alloy content for fast breeder reactors. Since higher burnups are promised in oxide fuels, a substantial portion of the program is being devoted to the development of improved oxide fuels.

Development of technology facilitating use of both U and Th in operating reactors, ultimately obtaining breeding in each cycle, is another important objective—the bulk of experience on reactor fuels is still on a fuel cycle based on metallic U.

**Ceramics.** Another direction for thermal-reactor fuel research is toward ceramic compounds, since an apparent limit on reactor operating temperatures and fuel burnup is imposed by swelling of metallic fuels at operating temperatures >400° C.

This swelling is due in part to fission-product gases. When four atoms of $U^{235}$ are fissioned, one of the eight fission-product atoms formed either is, or soon becomes, an atom of rare gas, xenon or krypton. This means that when only 1% of the atoms in a cubic centimeter of the metal has fissioned, some 4.4 cc. of these gases (at standard conditions) have been produced. These rare gases are practically insoluble in U. Hence, the Xe and Kr are in effect under very high pressure within the solid fuel lattice structure.

Current data indicate that the maximum achievable magnitude of burnup for metallic fuel is inversely related to the temperature of the fuel during irradiation: that is, with higher fuel-element temperatures, burnup is decreased. A theory used in explaining this behavior is that metallic U becomes weaker at high temperatures, permitting the expansion of internal fission-product gases to increase the size of the fuel elements by swelling to unacceptable limits. A considerable amount of research and development is being directed toward achieving higher burnups of metallic fuel at higher temperatures by: (a) increasing the elevated-temperature fuel strength, (b) increasing mechanical strength of fuel-element sheaths, (c) releasing fission gases by controlled porosity of fuel.

There are several other methods of overcoming the swelling problem. One is the use of a dispersion-type fuel consisting of a fuel phase dispersed in a ductile metallic matrix containing essentially no fuel—for example, $UAl_4$ in aluminum. Another is to use high-density ceramic materials, notably $UO_2$. A third is to use a sufficiently strong cladding to prevent fuel swelling by mechanical means.

All these approaches are under study at a number of laboratories, both here and abroad. In fact this is an area where many of the extensive investigations on military reactors are directly applicable to the civilian program. Based on present technology and limited data, it is believed that oxide fuels exhibit improved performance as compared with metallic fuels. More operating experience is required before a thorough comparison can be made, but fuels appear to have inherently better resistance to irradiation damage as compared with U-alloy fuels. The emphasis, therefore, has been placed on the development and production of ceramic fuels—greatest effort being on utilization of U-oxide fuels.

The ideal ceramic fuel has a number of characteristics, all unlikely to be found in one compound: a high melting point, low neutron absorption, inertness to cladding and coolant, homogeneity, high-temperature irradiation stability, high thermal conductivity, high U density, and good mechanical strength. The compound of $UO_2$ fulfills many of these requirements, but it lacks structural strength, has a low density and poor thermal conductivity. Although most effort so far has been directed toward use of $UO_2$ as a fuel its deficiencies are recognized.

In view of the large burnups reported for $UO_2$ fuel elements (some have gone as high as 30,000 Mwd/ton with little dimensional change) the research and development in this field will be concentrated on improving physical and mechanical properties of oxide fuels and on making fuel-fabrication techniques more simple and less expensive. Work is being done on mixed oxides of U and additives such as beryllium oxide and zirconium oxides. Such additives have shown promise in improving thermal shock resistance and fission-product gas release.

Other types of $U^{235}$ fuels also have promise: uranium carbide has better thermal conductivity and moderating properties than uranium oxide; uranium nitride has high U density. Improvement in irradiation behavior is a direct means of achieving lower fuel costs. The possibility of developing a fissionable ceramic for effective use at higher reactor temperatures is quite encouraging.

**Fabrication.** Fabrication development undertaken to simplify the manufacture of metallic and oxide fuel elements, in hope of lowering their costs, is of prime concern to AEC's program. For metallic elements, promising fabrication methods such as swaging, coextrusion, injection casting, are being tried; for oxide elements, a similar development program is underway. A definite determination of the limits for use of $UO_2$ is being undertaken.

For breeder and converter reactors having two-region cores, with metallic depleted-U blankets, exposure level has been limited to about 4,000 Mwd/ton. The development of inexpensive U alloys to increase the exposure levels will contribute to lower reactor operating costs. Under this program, investigations are being undertaken to determine the irradiation resistance of natural (or depleted) U containing molybdenum, niobium, and zirconium. Preliminary evidence indicates that 2½% molybdenum may withstand exposures exceeding 10,000 Mwd/ton at temperatures of 385° C.

Work will continue on metallic fuels, since they are particularly important to the prospect of utilizing natural U. Research programs are active on the development of U, Th, and Pu as fuels; alloys of U, Th, and Pu with each other or with other elements are of

## Fuel-Element Standards?

**The designers of reactors and fuel elements are being requested to compile a unified set of standards with the purpose of easing tolerances and restrictive specifications. Although no evidence is available, it is possible that present fuel element criteria may be more restrictive than is necessary, and thus conducive to increased unit production costs.**

interest in achieving this goal. Combinations of fissionable and fertile oxide as fuels have interesting possibilities. Dispersion combinations of metals in metals, ceramics in metals, ceramics in ceramics, compounds in compounds, and ceramics in alloys may be well adapted to long-life high-temperature operation in reactor cores.

## Bred Fuels

Another important area in fuel technology which should be accelerated is the use of "man-made" fissionable materials as fuel in power reactors. The use of $U^{233}$ and $Pu^{239}$ as fuels has been delayed both by difficulties inherent in handling these toxic isotopes and by the emphasis on their military applications. The Commission is solidly behind the Pu recycle and Th-$U^{233}$ fuel cycle programs. The thorium conference held at Brookhaven National Laboratory January 9–10, 1958 [see p. 91 for a report on that meeting—Ed.] and the plutonium conference held at Hanford April 22–23, 1958, brought together all data from the major activities in each of these two areas of nuclear fuel development.

**Thorium cycle.** The Th-$U^{233}$ fuel cycle has not heretofore had extensive testing as fuel in a heterogeneous reactor system. Use of this fuel cycle in thermal reactors could increase their conversion ratios materially. The metal appears to be an excellent fertile material because of its improved irradiation resistance as compared to U metal. However, there are other disadvantages in using Th: (a) the difficulty of reducing Th salts to the metal; (b) the high melting-point of the metal, increasing cost of producing ingots; (c) the chemical reactivity of Th at fabrication temperatures, requiring protective measures which complicate fabrication. One area of development is the investigation of fabrication processes that appear to have promise in simplifying operations. Fabrication by coextrusion could be a promising method.

Metallic $U^{233}$ behaves similarly to other U isotopes metallurgically and does not require research attention in this area. However, the rapid increase of radioactivity in reprocessed $U^{233}$ has resulted in production and fabrication problems causing increased costs. A very important goal of investigation is to develop cheap and remote methods of fabricating "hot" $U^{233}$ fuel. A promising avenue of research is the successful development and application of injection-casting to remote fabrication methods for thermal reactor fuel elements.

At this stage in the technology, the optimum fuel cycle may be based either on the use of the fissionable and fertile materials in their metallic or nonmetallic states. Thus it appears mandatory that development be underway simultaneously on both metallic and nonmetallic fuel cycles until sufficient data are obtained to permit an objective comparison to be made. An equal effort must therefore be devoted to the use of oxides of $U^{233}$ and Th. Such a program includes an extensive investigation of the irradiation behavior of these oxides as a function of temperature, methods of fabrication, and influence of ceramic additives.

There are several important reactor development projects going forward that employ Th as fertile material and require $U^{233}$ as the fissionable material. Many critical experiments need to be carried out in these programs over the next few years. Although some of the needed basic physics data are available from which to make approximate reactivity calculations, critical experiments are essential for each specific reactor type in order to confirm the assumptions in the calculations, especially at elevated temperatures. A study recently completed indicates that 60 kg of $U^{233}$ is needed this coming year and 80 kg in 1960 to support the minimum Th–$U^{233}$ development program. A really comprehensive program would require more than ten times this amount by 1960. Considerations are now being given by AEC to these needs.

To date, no reactor has been operated on $U^{233}$. We believe that actual reactor operating experience using $U^{233}$ is needed as part of the evaluation of this nuclear fuel. As a first step we plan to operate the MTR with a full set of $U^{233}$ fuel elements. As now planned, the fabrication and use of these fuel elements will follow the already-announced plan to operate the MTR on Pu (NU, Dec., '57, 25). These integral experiments should serve as valuable checks on the basic nuclear data as well as demonstrations in a limited way of the feasibility of fabricating fuel elements containing these toxic materials.

**Plutonium cycle.** Operation of MTR on Pu fuel is scheduled to begin this year. The Plutonium Recycle Test Reactor (PRTR) is under construction at Hanford, but operation of this facility is not scheduled until 1960. Likewise, the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) and the Pu loadings in the Experimental Breeder Reactors are not likely to provide operating experience with Pu fuel before late 1960 or early 1961. This means that there is a serious hiatus in the Pu fuel development program. By calling attention to this situation, we wish to stimulate investigators to develop ideas more quickly on the use of Pu fuels in power reactors.

Operation of MTR on 20%-enriched fuel was completed successfully last fall as a demonstration of the practicality of using so low an enrichment. Until recently our bilateral agreements limited the enrichment of exported U to this level for all except test reactors, so another area in our fuel development program is that of providing fuel elements for foreign power reactors under cooperative arrangements such as that now being discussed for the Euratom group. In order for a foreign utility to estimate with any reasonable reliability the cost of the nuclear power to be produced, it is essential that there be some assurance that the fuel can be carried to the predicted burnup. The proposed cooperative program with Euratom provides government guarantees of fabrication costs and physical integrity of fuel elements. The guarantees are in the form of U. S. Government assistance to American manufacturers rather than to foreign utilities. Thus the foreign fuel program and the fuel recycle program should prove of direct value in lowering nuclear power cost both in the U. S. and in Europe.

## Conclusion

We have attempted briefly to give an indication of the scope and urgency of the fuel-cycle development program. Encouragement can be taken from the interest of the Commission in an expanded and accelerated program. There are many problems to be solved, among the most important of which are the fuel lifetime, the reduction in cost of chemical processing and waste disposal, the reduction in cost of fuel fabrication and the development of Pu and $U^{233}$ as fuels for power reactors.

# U. S. Export Policies

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**ABOVE, SIGNING of U. S.-West German bilateral agreement last year by (from left): C. Burke Elbrick, State Dept.; Heinz L. Krekeler, West German ambassador; and Lewis L. Strauss, AEC chairman. LEFT, SHIPMENT of uranyl sulfate last month to research reactor in Berlin. Fuel was delivered to AEC at Idlewild by John Viverito, Mallinckrodt (right). AEC'S H. V. Werner (left) signed it over to Eduard Hess, West Germany.**

ONE OF THE BASIC building blocks of the United States Atoms for Peace program is the supply of nuclear materials essential to peaceful atomic development. In his historic address before the United Nations on Dec. 8, 1953, President Eisenhower made the proposal that the producing nations of the world make available adequate amounts of fissionable material for peaceful uses. Since the passage of the Atomic Energy Act of 1954, the United States has made available 100,000 kg of $U^{235}$ for peaceful purposes at home and abroad. Of this amount 5,000 kg have already been offered to the International Atomic Energy Agency, together with an offer to match the total amount of such material made available to the Agency through Dec. 31, 1960.

During the last four years, the Atomic Energy Commission has announced a number of policies which, in the aggregate, establish the terms and conditions of availability from the U. S. of the principal nuclear materials and related services. The purpose of this article is to summarize these conditions and to describe the principles behind them.

## Guiding Policies

Before discussing individual nuclear materials, it is worthwhile to identify certain principles which are generally applicable to the distribution of material or supply of services by AEC. First, to the maximum possible extent, materials and services are offered abroad at the same prices and under the same terms and conditions as are applicable domestically. Materials and services available from the AEC are priced without profit or loss, and are provided by the AEC only to the extent they are not available commercially at reasonable prices.

Second, materials will be made available only under appropriate safeguards to prevent their diversion to military purposes. Enriched U and other fissionable materials defined as "special nuclear material" by the Atomic Energy Act of 1954 ($U^{235}$, $U^{233}$, Pu) may be distributed abroad only under

Agreements for Cooperation between the U. S. and the cooperating nation or organization. For materials other than "special nuclear material," such as natural U, depleted U and heavy water, transfers need not take place under an agreement. But in the absence of such an agreement, comparable guarantees and safeguards are required in the sales agreement or through other appropriate means.

Agreements for Cooperation fall into two general types: *research agreements*, which provide for the transfer of limited amounts of enriched U for research reactor use; and *comprehensive agreements*, which provide for the transfer of larger amounts of material for power or other large-scale reactors, as well as for research reactors.

For research agreements, the safeguard provisions are relatively simple, providing principally for the right to observe from time to time the operation of the reactor and condition of the fuel. In comprehensive agreements, more far-reaching provisions are included, such as rights of inspection, review of design and the option to purchase by-product Pu or $U^{233}$ produced as a result of the use of any material or equipment transferred by the U. S. (in excess of the peaceful requirements of the cooperating nation).

## Enriched Uranium

The most important nuclear material available from the U. S. is enriched U. As noted, the President has determined that 50,000 kg of $U^{235}$ are available for foreign peaceful uses. This material will be distributed as needed, over a period of years, so that individual projects may receive assurance of a fuel supply over a period of time adequate for economic and financing purposes. It should be noted that the quantity made available is the quantity of $U^{235}$ contained in highly enriched U, *or its equivalent at other assays*. Thus, the actual quantity of $U^{235}$ available for distribution will depend on the isotopic assay of that distributed. An allotment of $U^{235}$ assayed at less than full enrichment may cost no more than a smaller allotment fully enriched. Because the U generally will be substantially less than highly enriched, the quantity of contained $U^{235}$ available for foreign distribution will be substantially greater than 50,000 kg (*1*).

Agreements remain in force for fixed periods of years and provide generally for the transfer of specific maximum quantities of enriched U. In research agreements, the quantity specified is normally 6 kg (initial full charge); however, in certain cases 12 kg has been provided under this type of agreement. In addition, the U. S. agrees to provide such additional amounts as necessary, over the period of the agreement, for the efficient use of the reactors; for example, delivery of replacement fuel while spent fuel is undergoing decay cooling and replacement of damaged fuel materials.

In comprehensive agreements, the quantities of enriched U are arrived at through consultation with the cooperating nation, and are designed to be adequate to provide fuel over the life of the agreement for projects which, at the time, appear reasonably firm. Once these quantities are established, however, they need not be employed in the firm projects; rather, they are available for use in any defined project which the cooperating government, in consultation with the U. S., wishes to undertake.

The fuel quantities in comprehensive agreements are specified in terms of a *net* amount $U^{235}$ defined as the difference between the amount transferred to the cooperating nation less the amount returned to the U. S. over the life of the agreement. It covers the cumulative amount of $U^{235}$ consumed over the term of the agreement plus the amount in the reactor inventory and the overseas portion of the "pipeline." The amount of material in the U. S. portion of the pipeline (under fabrication, processing, etc.) is not charged against this total.

## Long-Term Assurances

The U. S. has taken several steps in recognition of the importance of providing long-term assurances of fuel supplies. Most importantly, the U. S. is prepared to enter into agreements for periods longer than the original 10 years specified in early agreements. Under this policy, agreements providing for fuel supply over a 20-year period have now been negotiated (Italy, Japan, Euratom).

Further, the Commission has sought to provide reasonable assurance that developing atomic-energy programs abroad will not be limited by the availability of fuel. In his first announcement of the allocation of a large quantity of enriched U on February 22, 1956, President Eisenhower noted: "As additional projects are undertaken by our industry and by other nations, more nuclear fuel will be required. The AEC has informed me that it will recommend additional supplies be made available as they become necessary in the future." The Commission has also made it clear that the supply of fuel from the U. S. is not tied to the use of reactors manufactured in the U. S.

These factors, together with the favorable U supply situation in the U. S. and elsewhere, indicate that no serious concern need be felt as to the future availability of enriched U.

## Percentage Enrichment

Agreements for Cooperation generally provide that enriched U supplied by the U. S. will be at an assay, or $U^{235}$ concentration, not to exceed 20%. However, under some comprehensive agreements, the Commission has agreed to supply U enriched up to 90% for use in materials test reactors. On April 25, 1958, this policy was further liberalized to provide for the distribution of highly enriched material for use in research reactors also (*2*). Highly enriched material will be provided for either of these purposes only under comprehensive agreements for cooperation. However, the Commission is ready to consider requests for amendment to existing comprehensive agreements to provide for the transfer of highly enriched fuel.

In addition to the exception for

## U. S.-Euratom Agreement

**AEC recently negotiated and submitted to Congress a joint program with Euratom looking toward the installation of 1 million kw(e) of nuclear electric capacity in the Euratom nations by 1963. The program proposes a number of special arrangements for the fuel cycle (NU, July '58, p. 24). These arrangements would supplement—but not basically modify—the principles of supply of materials and services discussed in this article. They are applicable only to the 1-million-kw program.**

research and materials test reactors, the more recently negotiated agreements of both research and comprehensive types provide for the transfer of gram quantities of highly enriched U, Pu and $U^{233}$ for small-scale research purposes. The Commission is prepared to consider adding these provisions to earlier agreements.

## Price Schedules

The price schedule for enriched U, as well as general conditions of such distribution, was announced November 18, 1956 (*3*). The schedule is based upon the well-known ideal-cascade theory, which provides a means for calculating the value of product at any enrichment as a function of the two parameters of cost of feed and cost of separative work.

Although the price of enriched U is not guaranteed, the Commission has frequently stated its intention to keep the price as stable as possible. In view of AEC policy to establish prices reflecting costs and because the principal cost elements in the production of enriched U are the cost of feed and electric power, there is good reason to believe these prices will remain stable, as they have since established in January, 1955.

Enriched U is made available in the form of $UF_6$ (*4*) in keeping with AEC policy to depend on private industry to perform processing and fabrication services whenever possible. U. S. firms can convert enriched $UF_6$ into metal, oxides and other compounds (*5*). [See p. 11 for a NUCLEONICS survey of suppliers—Ed.]

## Export

Under the Atomic Energy Act of 1954, only AEC may export enriched U or other "special nuclear material." Further, all such material in the U. S. is the property of the government and is distributed for private use within the U. S. under license. These legal requirements, as well as practical considerations, have led to the development of a specific procedure for the transfer of enriched U abroad. First, the foreign government (representing, when appropriate, the organization under its jurisdiction which will utilize the material) selects a U. S. firm to process or fabricate the fuel and so advises AEC. AEC then makes available to this firm, under its license, the necessary special nuclear material. Upon completion of processing and fabrication and acceptance by the customer, AEC authorizes the shipment of the material to an agreed port of embarkation. At this point, transfer is made from the licensee to AEC, and from the AEC to the foreign government. The actual transfer takes place under a previously negotiated contract of sale or lease between AEC and the foreign government, in which the price and other terms are specified (*6*).

During the period when material to be transferred is being processed or fabricated the U. S. licensee is financially responsible for the material to AEC—subject to the same terms and conditions, including the 4% use charge, which are applicable to material distributed for domestic end uses, whether the material is to be transferred abroad by lease or by sale.

All commercial aspects of the transaction are matters for mutual agreement between the U. S. firm and its customer. Under AEC policy, the firm is responsible to the Commission for the material while in transit to the port of embarkation. However, it is free to pass along all or any part of this cost to the customer. Similarly, the use charge on the material while in process and transit, as well as the cost of any losses, is a legitimate business expense and would normally be passed along to the customer. In virtually all the cases which have come to the attention of the AEC, the processor or fabricator has guaranteed that losses will not exceed a fixed amount.

Upon transfer of the enriched U to the cooperating government at the port of embarkation, that government becomes financially responsible for the material to the AEC. This does not preclude, however, the foreign government's passing along this responsibility to others, such as the using organization.

## Lease and Sale

Enriched U supplied under research agreements is leased under terms and conditions essentially the same as those applicable domestically. The charge is a percentage (currently 4%) of the value of the material when leased. The specific lease agreement may provide for periodic settlements for consumption of fuel or for settlement upon return of the material.

The present policy of AEC is to sell—not lease—enriched U for use in foreign power reactors. This policy has naturally given rise to many questions. However, the reason behind it is quite simple and direct. The cost of the fuel inventory is a part of the capital cost of the reactor. Thus it should be borne by the owner of the facility. It is recognized that the cost of the fuel inventory is quite significant. For example, the inventory cost for a 200-Mw(e) pressurized-water reactor, including material in the "pipeline," is usually estimated at about $20-million. (If the fuel is fabricated and reprocessed in the U. S. a significant portion would be in the domestic part of the pipeline and would be leased.) Clearly, when atomic power comes into general use, the value of the fuel inventory in the aggregate will quickly reach billions of dollars. The financing of such large sums of money is properly a banking function. The U. S. Export-Import Bank, recognizing this, has indicated its willingness to consider financing the fuel inventory of foreign reactors.

It is appreciated that pioneer nuclear power plants will involve higher than normal costs, and may require special forms of assistance (such as special financing arrangements, for example) which could not be extended to future projects built on a strictly competitive basis. This factor would be given careful consideration by the Commission in any review of its policy on distribution of fuel for power reactors.

All transactions involving the distribution of enriched fuel abroad, by sale or lease, are carried out on a government-to-government basis. Agreements for Cooperation that provide for the sale of enriched U also provide that the cooperating government will retain title to the material supplied to it as long as the government in this country is required to retain the ownership of such material.

Under research agreements, spent fuel must be returned to the U. S. for reprocessing. It will be credited against the account of the cooperating nation at the value derived from the price schedule at the time of original transfer of enriched U. Under comprehensive agreements, provision is made for the possibility of reprocessing outside the U. S. However, material which is returned to the U. S. for reprocessing and is repurchased by the

U. S. also will be credited at the going price.

## Buy-back of Pu and $U^{233}$

Under its comprehensive agreements, the U. S. has reserved an option to purchase all Pu or $U^{233}$ produced in reactors fueled with material it supplied (in excess of the needs of the cooperating nation for peaceful purposes). In the November 18, 1956, announcement by President Eisenhower, it was indicated that AEC stands ready to purchase all such material through June 30, 1963; material so acquired will be used solely for peaceful purposes. This purchase offer is necessarily subject to the availability of appropriated funds on an annual basis, since the 1954 Act does not authorize AEC to enter into long-term purchase commitments abroad. The prices established through the period ending June 30, 1963, are $12/gm for Pu (in metal form) and $15/gm for $U^{233}$ (in nitrate solution).

It should be noted that this offer did not constitute a notice that the Commission intends to exercise the option granted by its Agreements for Cooperation to purchase all material excess to the needs of the cooperating nation, but rather was an offer to purchase only those quantities which are offered to the Commission.

The U. S. also reserves in its Agreements for Cooperation the right to approve transfer to other nations of any fissionable material not purchased by it and to require safeguarded storage of this material.

## Natural and Depleted U

Natural U is available in the U. S. from a number of private producers of concentrates and in processed or fabricated form from a number of other firms. Under a policy announced on May 8, 1958, such materials are obtained directly from the private producers (*7*). As in the case of enriched U, the distribution of these materials abroad is made under appropriate safeguards. The distribution procedures, however, differ from those for enriched U, because export by private firms, under license, is permitted. (Minor amounts of natural U—cumulative shipments of up to 100 kg contained normal U to a single consignee—may be exported without governmental assurances.)

Depleted U is available in a range of $U^{235}$ concentrations down to 0.22%. Like enriched U, this material is available from AEC in the form of $UF_6$ with any subsequent processing being performed by private firms. Distribution is made under export license, subject to satisfactory information concerning proposed use.

Prices for depleted U are based on an extension of the price scale for enriched U down to a minimum of $5/kg U, which occurs at 0.36% of $U^{235}$ concentration. When depleted U is supplied for any use where the assay is not important, such as for shielding purposes, the minimum assay of 0.22% will be supplied (*8*).

## Chemical Reprocessing

The only important service in the nuclear fuel cycle not commercially available in the U. S. is the processing of spent irradiated fuel and the related task of storage or disposal of radioactive wastes. However, the Commission announced on February 18, 1957, that it was prepared to enter into contracts with domestic reactor operators for fuel processing through June 30, 1967, subject to the condition that AEC could terminate the contracts upon one year's notice if processing services become commercially available at reasonable prices (*9*).

Under existing law, the Commission cannot make long-term commitments for processing services to foreign reactor operators; such processing would be provided under annual agreements.

For materials under lease from AEC, the lease charge remains in effect during the normal processing period. By analogy, in the case of purchased material, credits for repurchase would become effective as of the date of completion of this normal processing period. In each of these cases, "the normal processing period" is the time ordinarily required for processing if begun promptly on receipt of the material; thus the user is not penalized if AEC decides to defer processing.

The Commission's processing charges cover the recovery of U and Pu in the form of nitrate solutions and the permanent storage or disposal of radioactive wastes. Additional charges are made for conversion of $U^{235}$ nitrate to $UF_6$ and of Pu nitrate to metal (*10*).

It is quite possible that mutually beneficial arrangements can be worked out among reactor operators and fuel processors, under which, for example, the spent fuel from one reactor could be used as feed for another operating at somewhat lower enrichments, avoiding the cost of conversion to $UF_6$. Minor adjustments in $U^{235}$ concentration can often be made by blending at lower cost than through conversion to $UF_6$ and reconversion of $UF_6$ to the desired compound.

Most research and test reactor fuels can be processed through the assumed plant at a rate of approximately 20 kg of $U^{235}$ per day. But, for the small and infrequent batches discharged from research reactors, the principal charge would be the approximately $46,000 required for the three-day minimum plant cleanout. This problem could be alleviated by combining fuel from several reactors of similar type.

The AEC processing charges are f.o.b. the AEC processing plant. For most slightly enriched fuels, this location is likely to be the Hanford Works, Richland, Wash.; for highly enriched fuels, the probable location is the Idaho Chemical Processing Plant, Idaho Falls, Idaho (*11*). The foreign government is financially responsible for the material until its receipt at the AEC plant. After its receipt at a port of entry, however, it may be transferred to a U. S. licensee for shipment to the processing plant.

To ensure that adequate health and safety precautions are observed, shipment to the U. S. must be made in accordance with procedures approved by AEC and with the regulations of the U. S. Coast Guard and Interstate Commerce Commission.

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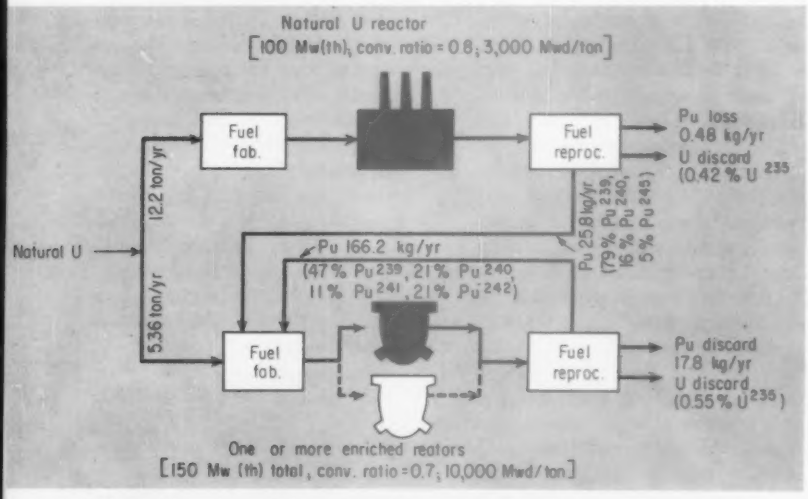
# URANIUM

The technology and prospects of U fuel in four parts:

1. The Case for Enriched Uranium (this page)
2. The Case for Natural Uranium (p. 88)
3. Uranium Alloys (p. 89)
4. Uranium Oxide (p. 90)


Natural U reactor
[100 Mw(th), conv. ratio = 0.8; 3,000 Mwd/ton]
Fuel fab.
Fuel reproc.
Pu loss 0.48 kg/yr
U discard (0.42 % U 235
12.2 ton/yr
Pu 25.8 kg/yr (79 % Pu 239, 16 % Pu 240, 5 % Pu 241)
Natural U
Pu 166.2 kg/yr (47 % Pu 239, 21 % Pu 240, 11 % Pu 241, 21 % Pu 242)
5.36 ton/yr
Fuel fab.
Fuel reproc.
Pu discard 17.8 kg/yr
U discard (0.55 % U 235)
One or more enriched reators
[150 Mw (th) total, conv. ratio = 0.7; 10,000 Mwd/ton]

## Will Natural and Enriched U Coexist?

**An extension of the Pu recycle system is the combination of natural- and enriched-U reactor systems. Such a Pu feeder-converter complex is shown in the figure. Natural U is fed to the "feeder" reactor which discharges fuel after ~3,000-Mwd/ton irradiation. The Pu produced is extracted and fed into the fuel cycle for the enriched reactor plants. In addition the enriched reactor plants will burn natural U and their self-produced Pu. The system shown assumes a 100-Mw(th) natural-U reactor with an initial conversion ratio of 0.8. With an enriched-reactor conversion ratio of 0.7, this particular combination would permit 150 Mw(th) of enriched reactors to be operated in conjunction with the 100-Mw(th) natural-U reactor as a self-sufficient complex. This feeder-converter system would permit complete independence from diffusion plants. In addition, power reactors in which enrichment is indispensable, as, for example, small power stations and nuclear propulsion, could be supplied with fuel from the system.**

# 1. The Case

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THE PRINCIPAL REASON that the U. S. civilian nuclear-power program has concentrated almost exclusively on enriched-U reactor concepts has been the consistent indication that power from such reactors will cost less than power from natural U reactors.

In brief, all natural U systems appear to require a much higher capital investment than enriched systems but have the possibility of a lower fuel cycle cost. Thus, in those economies where the capital investment is carried at very low fixed charge rates, the natural U fuel cycle is attractive. However, in economies where the fixed charge rates are similar to those in the U. S., the lower capital costs of enriched reactors balance the situation and, depending upon the degree of optimism, it continues to appear that the enriched systems have greater potential for producing low-cost power.

The engineering advantages of enrichment include a very wide latitude in the choice of reactor types and materials of construction, a smaller reactor size for a given power output and greater flexibility in the alloying, fabrication and burnup of fissionable fuels. The principal disadvantages are the higher basic fuel cost and the necessity for isotope separation plants and chemical reprocessing facilities.

**Diffusion-plant economics.** On purely economic grounds the capital investment in diffusion plants necessary to sustain a nuclear power system is only a small percentage of the total capital investment in the nuclear complex (*1*).

It has been shown that diffusion plants would account for about 5% of U. S. nuclear power plant investment projected to 1975, even assuming that all nuclear power plants use slightly enriched fuel.

In the year 2,000, assuming half of the enrichment comes from Pu recycle, the diffusion plant investment would be only about 2% of the projected

# for Enriched Uranium

U.S. nuclear power plant investment.*

In a similar way, if one considers the capital investment in chemical reprocessing facilities, these appear to be less than 10% of the total capital investment in the nuclear power plants. Again, this would assume that all nuclear fuel used in the world would have to be reprocessed.

With due recognition of the international strategic policies involved in planning the nuclear power programs of individual nations, sound economics will nevertheless result in nuclear power systems in many areas that depend on diffusion plants and chemical reprocessing plants.

**Pu recycling.** An additional factor leading to an enriched fuel technology is the development of the Pu recycle system (*2*). Although many practical problems and techniques in the handling of Pu have yet to be investigated, clearly the combined use of Pu fuel elements and natural-U fuel elements provide a substitute for enriched U that is independent of diffusion-plant enrichment facilities. Although at present the economics of Pu recycle can only be speculative, it will obviously be more costly than enriched-U fuel. Nevertheless, as soon as Pu is generally available as a fuel, it inevitably will be used.

On the assumption that Pu will have a fuel value, the chemical reprocessing of irradiated natural U becomes economically interesting. Even at our present costs of chemical reprocessing, and with Pu nominally valued at $12/gm, it is probably economically desirable to extract the Pu from irradiated natural U. Under such circumstances, chemical reprocessing plants would be associated with natural U systems; thus, one of the objections to enriched-fuel cycles disappears.

**Reactivity lifetime.** Studies of natural-U, $D_2O$ reactors have reached optimistic conclusions (*3*) based on the assumption that the reactivity lifetime can be stretched to allow burnup in the range 6,000 to 9,000 Mwd/ton. Other studies (*4, 5*), however, indicate that the reactivity available in a practical power reactor will limit burnup to 2,900–4,500 Mwd/ton and that the use of enriched U to extend burnup may more than pay for itself.

If long burnup of natural-U fuel cannot be achieved, the cost of the natural-U fuel cycle begins to approach that of the enriched cycle. In this regard, it is interesting that the relative cost of $U^{235}$ burned up in practical reactor operation does not vary over a very wide range when going from natural U to enriched U. For example, if the burnup is very low (about 1,000 Mwd/ton or less), a 1.5% enriched fuel is only 20% more costly than natural U. If a 50% burnup is assumed, the 1.5% fuel is 35% more costly. In most heterogeneous reactors, the actual burnups might be expected to be in the 50% range or less.

Due to the reactivity limitation in natural-U reactors, the effect of these cost differences can more than disappear in practice. For example, a natural-U reactor with an average burnup limitation of 3,000 Mwd/ton would produce heat at the same cost as a 1.5%-enriched reactor with an average burnup of 10,000 Mwd/ton. When one considers the advantages in terms of reactor cost and operation afforded by enriched fuel, the over-all plant economics may be significantly lower with the enriched reactor. For example, in the case of 50% burnups mentioned above, if the use of enriched fuel permitted a high temperature reactor configuration so that the thermal efficiency might be raised from 25% to 35%, this would exactly compensate for the higher cost of the enriched fuel, even if the burnup limitations were the same.

Moreover, if the enriched fuels will permit exposures of 10,000 Mwd/ton or more, it appears that the fuel costs themselves for enriched cycles will be equal to or less than that of the natural-U cycles. Such high burnups seem to be possible for both metal alloys and for nonmetallic fuels. Although unalloyed-U metal is limited in burnup (especially above about 400° C), with alloying, burnups as high as 30,000 Mwd/ton can be obtained (*6*). Similarly, exposures of this magnitude have been achieved with $UO_2$. Although the development of such high burnup fuels is still in its early stages, there are many indications that economically successful fuels will be achieved in the near future.

Only the enriched reactors really permit taking full advantage of the maximum burnup capabilities of the fuels presently under development. The effect of such long burnups on fuel-cycle costs for any given reactor and fuel element involves many separate factors, but to a first approximation the fuel cycle cost can be taken to vary inversely as the square root of the exposure (Mwd/ton). As an example if in a practical enriched power reactor the fuel cycle costs, including all credits and charges, are 6 mills/kwhr with an average exposure of 2,000 Mwd/ton, an increase in this exposure to 8,000 Mwd/ton will reduce the fuel cycle costs to about 3 mills/kwhr. It is therefore evident that if burnups as great as 30,000 Mwd/ton can be achieved, enriched fuel cycle costs will be very low indeed.

One might therefore conclude that the pressure of both technical and economic developments will probably result in the predominant use of enriched fuel cycles on a world-wide basis.

* Eventually Pu production from fast-breeder reactors may decrease the demand for enriched U from diffusion plants. However, such reactors are unlikely to make a significant contribution for many decades so that diffusion plants will be economically justified for at least as long as the normal lifetime of this type of facility.

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# 2. The Case for Natural Uranium

By JOHN R. MENKE
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THE QUESTION of natural versus enriched U persists as one of the major issues in the nuclear field. In this country, natural U is considered almost exclusively in relation to heavy-water-moderated reactors. The reactivity limitations with other moderators, such as graphite, are too restrictive to permit good ultimate economics in the United States. (As a matter of fact, the British, who have been the leading proponents of the graphite natural-U systems, are considering the use of heavy water for their more advanced installations of the future.) At least as much of the interest in the natural-U, heavy-water system derives from the advantages of heavy water as it does from the advantages of natural U.

The term "natural uranium" itself requires definition. It has come to have a broader meaning than the strictly literal interpretation. From the supply standpoint, one is primarily concerned with the fuel feed stream to the reactor and not necessarily with the details of the core proper. Three cycles need to be considered:

- Natural-U feed, natural-U core composition with the option at all times of reprocessing after burning.
- Natural-U feed, Pu recycle as a source of enrichment with consequent requirement of reprocessing.
- Very slightly enriched feed, say 0.9% $U^{235}$, with optional reprocessing.

The latter two systems can be designed to permit operation with natural-U feed and core loadings at somewhat reduced performance. These three systems have been called "operable on natural-U."

If one examines the class of reactors that derives from natural U and heavy water, a number of important advantages become apparent. The first and most obvious is that they are capable of operation on a universally available fuel. For overseas application the significance of this fact is self-evident as far as both supply and foreign exchange are concerned. On the domestic scene, the free market which now exists for natural U is most attractive to utilities. Multiple and very large sources of immediate supply, natural price stabilization, less direct influence by military demand for enriched material are all of importance at home and abroad.

## Pu Recycle

The answer in many quarters has been that enriched reactors can quite generally be made to operate on Pu recycle in combination with a natural-U feed stream. However, Pu-recycle technology has not yet been demonstrated. That it will be developed is certain, even though it will probably take several years. But more important, recycle is possible with a natural-U feed stream only under very limited conditions. A practical recycle system requires a net conversion ratio approaching 0.75 and an enrichment in fissionable material of not much in excess of 1%. However, U. S. technology and experience until recently has emphasized the other end of the enrichment and conversion ratio regime. The typical 3% enrichment and 0.5-0.6 net conversion ratio are not suitable for Pu recycle.

## Fuel Utilization

Effective fuel utilization is an important advantage of natural-U systems. In the table, the inventory requirements of a natural-U, heavy-water system are compared with those of an enriched, light-water system. Both systems are designed for 200 Mw(e). Note that in spite of the higher exposure allowed and the lower reactor inventory the net energy obtained per unit of ore investment favors the natural-U system by a wide margin. However, this assumes no credit for the burned fuel. For the natural-U case this may not be unrealistic, since, until we learn to reprocess burned fuel economically, the best way might be to simply store the depleted fuel. For the enriched systems this would be too expensive. But, even with U recycle (not Pu for many years), the natural U equivalent of the enriched core loading (assuming burnout to 2%) is about 125 tons, still higher than the natural-U case with no recycle.

To increase significantly the utilization factors shown in the table, the world must depend on both Pu and U recycling. Because of its higher conversion ratio, the natural-U reactor will still give better utilization even with complete recycling. If $C$ is the conversion ratio, with recycling the amount of fissionable material in the original feed is multiplied (through conversion of $U^{238}$) by the factor $1/(1-C)$. We have already pointed out that $C$ for current enriched light water systems is 0.5–0.6; but natural-U heavy-water systems are capable of conversion ratios of 0.75–0.8. Thus the fuel utilization of the natural-U system will be better by a factor of about 2.

One cannot mention fuel utilization without commenting on the role of breeder reactors. Certainly the maximum potential for fuel utilization lies in the direction of breeders. Good converters can lift fuel utilization from the current few tenths of a percent range to several percent. It remains

*Continued on p. 95*

**Uranium Utilization for Typical Reactor Concepts**

| | *Natural U-$D_2O$* | *Enriched U-$H_2O$* |
|---|---|---|
| Power [Mw(e)] | 200 | 200 |
| Enrichment (% $U^{235}$) | 0.71 | 3.0 |
| Core inventory (tons U) | 100 | 50 |
| Natural U equivalent of core inventory (tons) | 100 | ~300* |
| Core exposure [Mw(th)d/ton] | 5,000 | 10,000 |
| Energy released [Mw(th)d] | 500,000 | 500,000 |
| Net energy released/ton of natural U [Mw(th)d/ton] | 5,000 | ~1,700 |

* Includes total U feed to diffusion plant for 3% enrichment without recycle (theoretical plant at 0.3% tails concentration assumed).

# 3. Uranium Alloys and Dispersions

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AS A NUCLEAR MATERIAL, unalloyed uranium has the disadvantages of extensive anisotropic dimensional changes and surface roughening under irradiation (*1*, *2*). Ideally the anisotropic effects in polycrystalline U can be eliminated by using a random grain orientation; surface smoothness is improved with a fine grain size. These conditions can be only approximately achieved in unalloyed U through techniques such as beta-quenching. However, certain alloying elements have been found to be highly effective when combined with suitable heat treatment and/or fabrication techniques in producing fine-grained randomly oriented material. These may be classified as alpha-phase, gamma-phase and Th-U alloys and U-dispersions and intermetallic compounds.

The first two types (alpha and gamma phase) each have the same crystal structure as the similarly named phase in unalloyed U. Alpha-phase alloys contain fairly small total quantities of alloy additions which, in many cases, are limited to elements with low capture cross sections.

The gamma-phase alloys presently of interest require greater amounts of alloying elements than do the alpha-phase alloys.

In dispersion-type materials the U is present as a separate phase (or phases) dispersed in an essentially sterile metal matrix, e.g., Al-U alloys. U of partial or high enrichment is required in all of the dispersion materials in use at the present time.

Important criteria for evaluating alloys are: nuclear suitability, irradiation behavior, corrosion resistance, fabrication factors and cost. Alloy cost is dependent somewhat on all of the other criteria and particularly upon fabrication technology. In some cases an especially facile manufacturing technique has given a new material a cost advantage, e.g., extrusion of $U_3O_8$ and aluminum powders directly into fuel strips for the Argonaut reactor. Because of space limitations only irradiation behavior and aqueous corrosion resistance will be treated here and only work done at ANL (unless stated otherwise) will be reported.

## Alpha-Phase Alloys

U metal alloyed with small amounts (0.1–0.4 wt%) of chromium has shown irradiation growth rates comparable to beta-quenched U but has maintained much better surface smoothness. The cast eutectic alloy (U-5 wt% Cr), however, is characterized by a large grain size and hence severe surface roughening.

U containing 1–3.5 wt% Mo is one of the most promising alpha-phase U alloys. The irradiation growth rate of swaged and heat-treated U-2.5 wt% Mo alloy, for example, is only about one-fourth that of beta-quenched U. Surface smoothness in the Mo-alloy specimens is also much better.

U-Pu alloys, which are of interest for fast reactors, generally behave poorly under irradiation. They are characterized by large grain sizes both in the cast condition and in extruded samples that have been heat treated to randomize grain orientation.

Zirconium is a highly useful addition to U since it has a low thermal absorption cross section and imparts good alloy properties. The addition of as little as 1.6 wt% significantly improves the grain size of U and makes the U amenable to heat treatment for virtual removal of preferred orientation. For example, the irradiation growth rate of swaged and heat-treated U-2 wt% Zr alloy is about one-fifth that shown by beta-quenched U. The ternary alloy, U-5 wt% Zr-1.5 wt% Nb, is also of interest because of its improved corrosion resistance (*3*) and good dimensional stability.

## Gamma-Phase Alloys

Gamma-phase U alloys are not subject to anisotropic growth but they necessarily contain larger additions of alloying elements. They are, therefore, chiefly of interest for use in fast reactors. For example, the U-10 wt% Mo alloy to be used as fuel material in the PRDC reactor is characterized by excellent dimensional stability and resistance to swelling when irradiated at elevated temperatures (*4*). The EBR-II reactor will use first a U alloy and later a U-Pu alloy as fuel materials (*5*). Both of these fuels also contain certain fission products (principally Mo and Ru) in a mixture which is known as "fissium." The U-fissium and U-Pu-fissium alloys are at least partially gamma phase, and they have been found to be highly resistant to irradiation damage. When extra Mo is used the alloys become completely gamma phase and are exceptionally stable under irradiation.

## U Dispersions

Materials of this type are very resistant to roughening and elongation even for burnups as high as 1 at%. Experience in the MTR and the many other research reactors that use a Al-U fuel has been very satisfactory.

## Intermetallic Compounds

Radiation tests of pure intermetallic compounds has been largely limited to $U_3Si$, generally known as the epsilon phase (3.8 wt% Si). Excellent surface characteristics are retained but some tendency for growth is shown in extruded materials. The Si alloy also possesses promising postirradiation high-temperature aqueous-corrosion resistance (*3*, *6*).

## Th-U Alloys

Dimensional changes in alloy composition ranging up to 5 wt% $U^{235}$ in Th are very slight, even at total atom burnup as high as 4.4%. These results are not surprising since Th and the alloys investigated are cubic.

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# 4. Uranium Oxide Experience

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$UO_2$, used either as a dispersion in cermet fuels or in the form of ceramic bodies, will undoubtedly play a major role in future nuclear power plants. Because of its physical properties and excellent resistance to radiation damage, $UO_2$ may be utilized in reactors operating at low, intermediate, and high temperatures.

On the basis of the present radiation damage data on $UO_2$, high burnups (greater than 25,000 Mwd/ton) appear feasible without appreciable damage to the $UO_2$ and the structural cladding material, provided the materials are properly prepared.

## $UO_2$ Fabrication

Urania ($UO_2$) can be fabricated by any of the following techniques:

- Cold compacting in dies and sintering
- Hydrostatic pressing and sintering
- Hot pressing
- Ceramic extrusion and sintering
- Slip casting and sintering
- Swaging

The density of the sintered $UO_2$ is controlled to a large extent by the particle size, surface area, and density of the $UO_2$ powder. A high surface area, high density, and small particle size are characteristics required to produce a uniform ceramic body of $UO_2$. Since the $UO_2$ is unstable at elevated temperatures in an oxidizing environment, sintering is usually performed in the presence of hydrogen or an inert atmosphere, at temperatures of 1,500° C and higher. The sinterability of $UO_2$ may be varied by additives such as $TiO_2$, $CaCO_3$, $Ce_2O_3$ etc., and also by sintering in a steam environment. The mass production of $UO_2$ pellets is possible by the adaptation of conventional powder-metallurgy techniques.

## Physical Properties

The refractory compound $UO_2$ has a high melting point (2,760 ± 30° C), no phase transformations when in contact with an inert atmosphere, good mechanical strength, and good corrosion resistance in high-pressure water of controlled chemistry—desirable properties for a reactor fuel. $UO_2$, however, also has undesirable physical characteristics, namely poor thermal conductivity, poor thermal-shock resistance, and high thermal coefficient of expansion. When $UO_2$ is used in a dispersion fuel element the poor thermal conductivity of $UO_2$ is of little importance since a high thermal conductivity metallic matrix surrounds the discrete particles of urania. However, in reactors where bulk $UO_2$ is used, the thermal characteristics must be factored into the design.

## Radiation Damage*

Sintered ceramic bodies of $UO_2$ exhibit good resistance to radiation damage. However, higher oxides of U such as $U_3O_8$ have a low degree of radiation stability. Bulk $UO_2$ fuels burned to approximately 25,000 Mwd/ton revealed no appreciable changes in density, structure, resistance to thermal fracture, thermal conductivity and resistance to corrosion in high pressure water. The release of fission-product gases, xenon and krypton from the irradiated $UO_2$ is diffusion-controlled and hence high-density $UO_2$ without interconnected pores releases only very small amounts of the gases.

High-density urania bodies (approximately 92–95% of theoretical density) are also highly resistant to damage by power cycling and highly resistant to erosion or release of solid oxide particles to water. No disintegration or powdering of high-density $UO_2$ occurs from irradiation. However, gross cracking results from imposed thermal gradients. These cracks generally occur in a radial pattern, and therefore, do not adversely affect the thermal conductivity of right cylinder $UO_2$ pellets. Chemical reprocessing of irradiated $UO_2$ fuels can be accomplished by present methods in existing reprocessing facilities.

## Fuel-Element Fabrication

$UO_2$ has been used successfully in dispersion-type fuel elements and ceramic fuel elements.

In the former, enriched $UO_2$ particles are dispersed in a ductile metallic matrix. These elements are prepared by powder metallurgy techniques and shaped by rolling or extrusion. Materials selected for the matrix should be chemically compatible with the $UO_2$. Typical matrix materials that have been used in dispersion-type elements are aluminum and austenitic stainless steels. Dispersion-type elements must be clad to retain fission gases and to protect the fuel from the coolant. Some examples of reactors that use dispersion-type fuel elements are the Geneva reactor (plate-type elements of $UO_2$ dispersed in aluminum and aluminum clad) and the Army Package Power Reactor ($UO_2$ dispersed in austenitic stainless steel and clad with stainless steel). By proper selection of matrix and cladding material, dispersion-type fuel elements may be used for low, intermediate, and high operating temperatures. The dispersion-type elements have excellent thermal conductivity, good thermal shock resistance and good strength.

Sintered ceramic shapes of $UO_2$ clad to prevent fission-product gas escape have also been used for fuel elements. Compatible cladding materials such as austenitic stainless steel and Zircaloy can be used. The thermal coefficient of expansion of stainless steel is greater than that of the $UO_2$, whereas the Zircaloy expansion is less than for $UO_2$. This factor is very important in fuel-element design. Where a gap exists between the fuel and cladding, a heat-transfer medium such as a gas may be desirable.

Sintered right-cylinder pellets of $UO_2$ prepared by powder metallurgy methods are presently being used in the blanket elements of the Shippingport pressurized-water reactor. Zircaloy is used as the cladding material. In the Yankee reactor, the fuel element consists of right cylinders of sintered $UO_2$ clad in austenitic stainless steel. $UO_2$ is also used in the Organic Moderated Reactor Experiment in the form of $UO_2$ plates clad in austenitic stainless steel. The fuel proposed for the Oak Ridge gas-cooled reactor study (see p. 119) consists of cored right-cylinder pellets of $UO_2$ clad with austenitic stainless steel.

* J. D. Eichenberg, P. W. Frank, T. J. Kisiel, B. Lustman, K. H. Vogel, Effects of irradiation on bulk $UO_2$, WAPD-183.

# THORIUM

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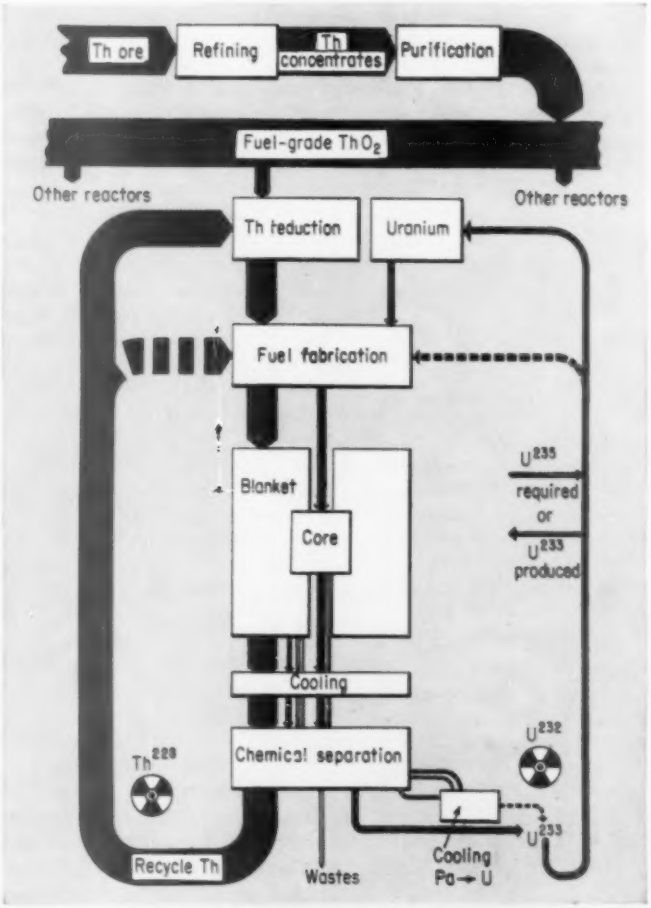


FIG. 1. Typical thorium-$U^{233}$ fuel cycle as drawn by F. T. Miles. Arrow widths are roughly proportional to mass flow rates. Radiation symbols indicate points in the cycle where radiation is a problem. Gray lines indicate waste streams.

THE THORIUM-$U^{233}$ FUEL CYCLE offers significant advantages to the reactor designer. Good supplies of Th are available. Reactor physics is straightforward—most of the parameters involved are already known for the thermal part of the neutron spectrum.

Th consists entirely of the fertile isotope $Th^{232}$. Neutron capture and two subsequent beta decays convert it into fissionable $U^{233}$. Thus the conversion is as follows

$$Th^{232}(n,\gamma)Th^{233} \xrightarrow[23.3\ \text{min}]{\beta} Pa^{233} \xrightarrow[27.4\ \text{day}]{\beta} U^{233}$$

Figure 1 shows a typical Th-$U^{233}$ cycle.

**Problems.** The main problems of Th-$U^{233}$ systems will come from the inherent radioactivity of the $Th^{232}$ decay chain. This will probably require remote fuel fabrication. It may lead also to pyrometallurgical processing. Since there is inherent radioactivity anyway, pyrometallurgy need not be penalized for incomplete separation of fission products.

To date no reactor has been operated on $U^{233}$. Hence, feasibility of its use as a fuel has not yet been established. As a first step the AEC is planning to operate the Materials Testing Reactor with a full set of $U^{233}$ fuel elements. As now planned, fabrication and use of these fuel elements will follow the already announced plan to operate MTR on Pu (NU, Dec. '57, p. 25).

A shortage of $U^{233}$ is one influence that has been holding up the development of the technology. (See box, p. 92). The AEC is attempting to define a policy that will correct this shortage. Meanwhile there is a need for further experiments with critical and subcritical assemblies to evaluate epithermal characteristics of this fuel cycle and test the predictions of reactor physicists.

## Reactor Physics

There do not appear to be any unusual problems in reactor physics with

Th-$U^{233}$ fuels. A good knowledge of basic parameters in the thermal region has already been acquired. Some new control problems may arise because of the delayed-neutron yield, which is smaller for $U^{233}$ than for $U^{235}$ (*1*).

**Cross sections.** The best available values for $Th^{232}$ and $U^{233}$ neutron cross sections at thermal energies are

| | | |
|---|---|---|
| capture, $Th^{232}$ | 7.43 ± 0.22 | barns |
| fission, $U^{233}$ | 532 ± 6 | barns |
| capture, $U^{233}$ | 588 ± 7 | barns |

When combined with the number of neutrons per fission $\nu$, the last two of these cross-section values lead to $\eta_{233} = 2.27$ for the number of fast neutrons emitted per thermal-neutron capture in $U^{233}$, which is in agreement with experiment. Oak Ridge National Laboratory work gives $\eta_{233} = 2.31$ based on $\eta_{235} = 2.08$. With variation in neutron energy, $\eta_{233}$ is essentially constant up to 1.0 ev, but beyond this it shows a sharp dip and rapid fluctuations. These fluctuations occur in the resonance region but apparently do not coincide with the cross-section resonances.

The following values for $\eta_{233}$ at higher energies have recently been reported: 2.25 at 30 kev, 2.43 at 140 kev, 2.45 at 250 kev and 2.60 at 900 kev (*2*). The last value is consistent with a value of 2.65 for the difference between neutrons per fission $\nu_{233}$ and capture-to-fission ratio $\alpha_{233}$ established by comparison with $U^{235}$ in the Topsy and Jezebel assemblies at Los Alamos.

**Resonance capture.** A recent determination of the resonance integral of Th is 96 ± 6 barns (*3*). This is in good agreement with the value calculated from known and assumed resonance parameters. One such calculation resulted in 67 barns for the first 7 resonances, 25 for the contribution of higher unresolved levels and 3 for the $1/v$ contribution for a total of 95 barns. A second calculation resulted in the same total based on 79 for the first 18 resonances, 13 for higher resonances and 3 for the $1/v$ part. This is to be contrasted with an earlier measurement of 67 ± 5 barns (*4*). Both of the experimental values have the $1/v$ portion subtracted.

These values for infinitely diluted samples are of less importance in reactor design than those for fuel in clusters. Consequently, there have been several recent determinations of the effective resonance integral of Th as a function of the surface-to-mass ratio.

A simple theoretical formula was used to compare the several sets of experimental values (*5*). It takes into account Doppler broadening and the possibility that a neutron enters a lump and escapes with collision.

Two checks on such data are possible. One involves the shape of the surface-mass-ratio dependence, and the second the scaling factor between similar measurements on metal and oxide samples. Three recent measurements on various samples of U, Th and their oxides agree with the shape expected theoretically (*6–8*). A fourth determination does not appear consistent on either the shape or scaling basis (*9*). Thus a systematic error is suspected.

A consistent value for the effective resonance integral is still lacking in the measurements reported on Th.

**Fast-fission factor.** No significant bonus is to be expected from fast fission of Th in contrast to $U^{238}$. This is a consequence of the higher threshold and lower fission cross section of $Th^{232}$. The lower value of the fast-fission factor $\epsilon$ has been confirmed by recent BNL measurements in lattice cells.

**Neutron age.** Measurements have been made of the neutron age in both light- and heavy-water systems containing moderate quantities of Th and $ThO_2$, but there are not enough experimental data to decide whether the ages for systems containing Th are in complete agreement with theory.

**Reactivity effects.** The yield of delayed neutrons in $U^{233}$ fission is only about 40% of that for $U^{235}$. This aggravates associated problems in reactor control because of the reduced margin between delayed and prompt critical (*11*).

A second major concern is the effect of $Pa^{233}$. The long half-life (27 days) and large capture cross section (~65 barns at thermal energies) of this intermediate product in the production of $U^{233}$ present a serious problem for the achievement of good neutron economy. Particularly in a maximum-performance reactor, burnup of $Pa^{233}$ represents a significant twofold loss of both useful neutrons and potential $U^{233}$ atoms.

**Thoria.** Small radiation damage and chemical compatibility with water make thoria fuel elements attractive for a long fuel cycle. There is a need for precise physics design work to provide a large initial conversion ratio.

## Th and $U^{233}$—Need and Availability

**Thorium presents no serious problems of availability. Ample supplies of ores, principally containing monazite, are available. Thorite-type ores occur extensively in the United States, but they have not been exploited yet. By-product Th from U mining may become of importance.**

**The present cost of Th metal is in the neighborhood of $20/lb. New processes that are being developed show promise of reducing the cost.**

**The Atomic Energy Commission indicates that 30 kg of $U^{233}$ is needed this year and 80 kg will be needed in 1960 to support the minimum Th-reactor-development program. A really comprehensive program would require more than 10 times this amount by 1960. Consideration is now being given to these needs, and it is hoped that the AEC will be able to produce enough material for these requirements.**

**The problem of pricing both $U^{233}$ and Th is a difficult one for the AEC. It has established a fair purchase price of $15/gm for $U^{233}$ in the form of uranyl nitrate and $30–45/gm for domestic plutonium metal, depending on $Pu^{240}$ content. Thus there is strong economic incentive to produce Pu for weapons as a by-product of power production rather than to produce $U^{233}$ as a replacement fuel for initial $U^{235}$.**

**"In fact," says Clark Goodman, formerly of the AEC Division of Reactor Development, "this pricing policy has caused several industrial organizations to seriously consider abandoning the Th-$U^{233}$ cycle in favor of the U-Pu cycle. In view of the long-term importance of thorium as a source of fissionable material, it is to be hoped that a pricing formula can be found that will be more favorable toward thorium but which will at the same time recognize the superior properties of plutonium for weapons purposes. All that can be said at present is that the Commission is well aware of this problem, but no equitable pricing plan has yet been evolved which encourages the use of Th in proper proportion to its fertility."**

With a large enough initial ratio, reactivity effects will not limit the useful life of the fuel elements.

The larger absorption cross section of thorium argues for systems less heterogeneous than in present $U^{235}$ reactors. Epithermal operation looks promising at present.

## Solid-Fuel Studies

There are considerable data on physical and metallurgical properties of Th, its alloys and $ThO_2$ in solid fuels. Their radiation stability appears to be encouraging, but more work is required to determine more fully their radiation characteristics.

Effects of small amounts of impurities including oxygen, nitrogen and carbon have been observed. Pure Th has been irradiated to 1.5% burnup of metal atoms with little change. Battelle Memorial Institute has thoroughly investigated Th binary-alloy systems, including ThC, ThBi, ThPb, ThZr, ThMg, ThCe, ThPu and ThU. ThZr shows promise as a water-corrosion-resistant alloy.

Alloys of U and Th have been studied and are still receiving investigation. Alloys of up to 5.5% $U^{235}$ in Th have been irradiated with excellent results to 4% burnup of total atoms at 50°–200° C in the MTR. Alloys of U and Th up to 28% uranium are being prepared for irradiation to several per cent burnup at temperatures up to 800° C or higher. Atomics International has irradiated 10% $U^{235}$-Th alloys to 0.35% burnup of total atoms at temperatures up to 1,250° F with volume increases of 5% (calculated). Although the diameter of a ⅜-in. pin increased 0.003–0.005 in., these alloys remained relatively ductile and appeared better than other U alloys tested.

Powder metallurgy of Th and of U-Th alloys has also been investigated. Thorium powders have been produced by the hydride process and by calcium reduction of $ThO_2$.

Cold-pressing Th powder to densities 95% of the theoretical value for pure metal can be performed at pressures of 75 ton/in². Sintering of powders in the 1,200°–1,600° C range was studied. Generally speaking, higher densities were obtained with higher sintering temperature. Hot pressing was also studied, and by control of the type of powder, pressures and temperatures, densities of 11.5 gm/cm³ were obtained.

$ThO_2$ and $ThO_2$-$UO_2$ bodies have been studied with composition of $UO_2$ in $ThO_2$ as high as 75%. $ThO_2$-$UO_2$ with $UO_2$ up to 30 wt% have been fired in air. Conventional methods of pressing powders and sintering were used. Irradiation studies at temperatures up to the melting point and 0.42 at. % burnup have been made on 10% $UO_2$-$ThO_2$ bodies. Some 6.36 wt % $UO_2$-$ThO_2$ bodies have been irradiated to 1% burnup at MTR temperatures with good dimensional stability.

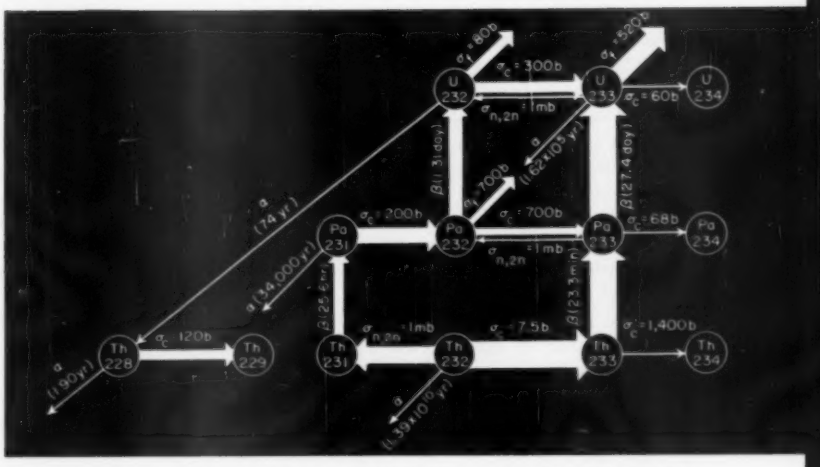


FIG. 2. Reactor production of $U^{233}$ from $Th^{232}$. Numbers show cross sections and half-lives of important processes

**Use in Con Ed Project.** Babcock and Wilcox are planning to use $UO_2$-$ThO_2$ bodies in the reactor to be built for Consolidated Edison at Indian Point, N. Y. High density, close tolerances without grinding and the use of commercially available powders are objectives. High-temperature loop tests in MTR to study stainless-clad $UO_2$-$ThO_2$ fuel elements are being initiated.

$ThO_2$-$UO_2$ bodies reinforced with Nb, Mo and Zr metal fibers show thermal-shock resistance and thermal-conductivity properties far superior to pure $ThO_2$. Methods of fabricating $ThO_2$ bodies have been thoroughly studied at Oak Ridge. Slip-casting techniques were least successful. Studies of calcining $ThO_2$ at various temperatures for use in homogeneous reactors indicate that $ThO_2$ calcined at 1,800° C results in the best slurries.

## Ore Processing

Present commercial production capacity for Th is 1,000,000 lb of $ThO_2$ annually. Four processes are available:

1. Solvent extraction of sludges has been used at the Fernald, Ohio, Feed Materials Center to produce Th of low U and rare-earth content. Among other methods one investigated at the Bureau of Mines is the reduction of halides to sponge metal, followed by arc melting.

2. The metallex process developed at Oak Ridge involves the reduction of the $ThCl_4$ by sodium amalgam to a powder. This can be directly extruded to Th rod.

3. A process successfully operated in a pilot plant at Horizons, Inc., Cleveland, Ohio, produces a crystalline Th readily adaptable to cold consolidation and arc melting and to warm ex-

### Advantages of the Th-$U^{233}$ Cycle

1. **High neutron yield $\eta$**
2. **Good radiation stability in metal and oxide fuels**
3. **Good adaptability to power systems with large conversion ratios**

### . . . and Its Disadvantages

1. **Small fast-fission factor $\epsilon$**
2. **Small delayed-neutron yield**
3. **Long half-life of the intermediate nuclide $Pa^{233}$**
4. **Radiation problems in recycling**

trusion to billets approaching 100% of the theoretical density of pure Th.

**4.** National Lead Co. produces Th powder by the reduction of $ThO_2$ with Ca. The powder can be hydraulically pressed into rods and from all indications can be arc melted into ingots.

Quality of the products, either oxide or metal, depends on the type of process that might be used in production. $ThO_2$ and some metallics appear to be the largest impurities. Iron, nickel, and aluminum are worth mentioning. What the levels of these impurities should be has not yet been defined. Rare-earth contents generally are less than 100 ppm.

## Chemical Reprocessing

When discussing reprocessing for Th-$U^{233}$ solid fuels, it is convenient to discuss alloys and $ThO_2$-$UO_2$ separately.

**Alloy fuel.** Fuels that employ metallic Th and U are amenable to low-decontamination processing by pyrometallurgical methods; alternatively they can be processed by the aqueous Thorex process (*10*). Three types of volatility processes are under development: direct volatilization, salt-bed processing and fused-salt electrolysis.

Pyrometallurgical processes should involve low capital costs, high capacity and small waste volumes. However, they require remote fabrication of fuel elements. This may not be a serious disadvantage in the Th cycle. Inherent radioactivity from $U^{232}$ decay will probably require remote handling in any case.

The direct volatilization process separates the Th and U from I, Xe, Kr, Cs and some of the rare earths but leaves the fuel contaminated with Zr, Mo and Ru. This method is relatively simple but gives low decontamination.

In the salt-bed process the molten Th-U alloy is contacted with salt, which extracts the fission- and corrosion-product impurities. I, Xe, Kr, Sr, Cs and the rare earths are removed. It is moderately effective for fission-product removal but suffers because some Th is lost to the salt phase.

Fused-salt electrolysis removes essentially all of the fission-product contaminants except Zr. While it provides the highest decontamination of the three pyrometallurgical processing methods, it is relatively complicated because several steps are required.

**$ThO_2$-$UO_2$.** Only aqueous processing via the Thorex route has been seriously considered for $ThO_2$-$UO_2$ mixtures. However, the radioactivity inherent in the Th-U cycle makes it impossible to realize the major advantage of the high-decontamination Thorex process. For this class of fuels, it is desirable to develop new, inexpensive reprocessing methods equivalent to pyrometallurgical processing.

**Aqueous processing.** The Thorex process has been developed at the Oak Ridge National Laboratory, Savannah River, and Knolls Atomic Power Laboratory. A 200-kg/day pilot plant has operated for three years at ORNL.

Major problems remaining in the Thorex program are increasing the separation of Th and Ru and decreasing Th losses. Processing extremely short-cooled Th would yield a Th product essentially free of the $U^{232}$ decay chain. The flow sheet should be demonstrated with Th cooled for significantly less than 30 days.

**$U^{233}$ separation.** In laboratory studies it has been demonstrated that the third cycle separates U from Th by a factor of $10^8$. Therefore the $U^{233}$ product immediately after processing should be free of $U^{232}$ decay-chain activity. However, on standing the activity in the U builds up, and it may be necessary to remove it before direct handling.

At Los Alamos, shielded glove-box equipment has been set up to accomplish this purification. In a typical run the surface activity level of a batch was reduced from 2 to 0.03 r/hr. Experiments at ORNL have shown that a chloride anion-exchange step yields 50–75-fold decontamination of the $U^{233}$ from Th and Ra while a $ThF_4$ scavenging precipitation yields 3–4-fold separation.

## Radiation Problems

The problems associated with recycling and handling of Th and $U^{233}$ can be divided into several categories—reactor irradiation, activity of recovered irradiated Th and $U^{233}$, handling of Th and $U^{233}$ after processing and allowable or workable specification for recovered products. The major problems in handling these materials are due to the external gamma-ray hazard from $U^{232}$-$Th^{228}$ daughters, or the internal hazard due to alpha contamination of air. The problem of spontaneous fission or $\alpha,n$ reactions, although present, appears secondary to the others.

**Reactor irradiation.** The formation of $U^{232}$ in the Th-$U^{233}$ system is shown in Fig. 2. The formation rate of $U^{232}$ is proportional to the $n,2n$ cross section of $Th^{232}$. The value of this cross section depends on how much fuel a Th element "sees" since only neutrons in excess of 6.37 Mev can cause $n,2n$ reactions. The apparent pile cross section is thus a function of the fast-thermal flux ratio for any given reactor. To achieve a low value for the $n,2n$ cross section we must "separate" the fast and thermal flux. However, to do so we pay the price of lower production rates for $U^{233}$ and low-power operation. Large $U^{232}$ content is associated with large $U^{233}$ production.

## Borax-4 Points the Way with Thorium

While no reactor has been fueled with $U^{233}$, some of the dynamics involved have been explored by charging the boiling-water experiment Borax-4 with $ThO_2$-$U^{235}O_2$ fuel (*11, 12*). The experiment went critical on December 3, 1956, and by the end of 1957 had produced 300 Mwd of heat.

The fuel elements have characteristics shown in the table. They are clad with aluminum containing 1% nickel and bonded with lead. A reactivity loss of 1% in about 250 Mwd was observed. This is not far from what might be expected in a $U^{235}$-fueled reactor with no burnable poison. The oxide fuel element has a relatively long thermal time constant of 0.9 sec. This leads to correspondingly higher fuel temperatures before shutdown on short reactor periods and presumably influences the power attainable. At 300 psig the 59-element loading has developed 14.4 Mw with 5.5% reactivity in steam voids, corresponding to 36 kw /liter of core or 56.5 kw/liter of coolant.

**Characteristics of Borax IV Fuel Elements:**

| | | | |
|---|---|---|---|
| Over-all length | 56.6 in. | Oxide diameter | 0.230 in. |
| Fuel length | 24.375 in. | Weight of $UO_2+ThO_2$ | |
| Cross section | 3.875 × 3.828 $in^2$ | per assembly | 5.425 kg |
| Fuel plate spacing | 0.604 in. | $U^{235}/ThO_2$ ratio | 0.0556 gm/gm |

FIG. 3. Decay scheme for $Th^{228}$, $Th^{232}$ and $U^{232}$. Major sources of inconvenient gamma activity are $Bi^{212}$ and $Tl^{208}$

**Irradiated Th and $U^{233}$.** The radiation intensities in recycled Th and $U^{233}$ are high enough to alter handling procedures during recycle. Major sources for high gamma activity are $Bi^{212}$ and $Tl^{208}$—decay daughters of $Th^{228}$. $Th^{228}$ is a natural decay product of $Th^{232}$, and therefore it is found in nature with its decay daughters. Additional $Th^{228}$ is produced by $U^{232}$ decay. The decay scheme indicating the characteristics of the decay daughters is shown in Fig. 3.

The gamma intensity at the surface of a 1-kg sphere of Th is 0.5 r/hr/ppm $Th^{228}$. The radiation intensity at the surface of a 1-kg sphere of $U^{233}$ is $0.04 + 0.01\,t$ r/hr/ppm $U^{232}$, where $t$ is the number of days since final separation. Other activity problems in $U^{233}$ are alpha emission, $\alpha,n$ reactions and spontaneous fission. Alpha emission is a problem in $Th^{232}$.

**Present handling techniques.** To date no recycled Th has been handled beyond chemical reprocessing. However, large quantities of natural Th have been handled at the Fernald site. There the external hazard was below tolerance, but air contamination was a major problem. It may be necessary to place the major operations in separate buildings and improve ventilation.

The experience in handling $U^{233}$ at Los Alamos has indicated that dry-box techniques must be used for all steps between $UO_2(NO_3)_2$ and finished $U^{233}$ metal.

In the metal areas, an average exposure of 0.7 rem/man-week has been acquired. If ion-exchange cleanup is used prior to chemical conversion, it should be possible to triple the throughput for the same personnel exposure.

In all cases to date Los Alamos has been handling $U^{233}$ containing an average of 20 ppm $U^{232}$. In the future $U^{233}$ fuels may contain 100–150 ppm $U^{232}$, and then it will be necessary to use increased shielding for dry boxes, shorter time schedules and more rotation of personnel from other areas.

The time for the manufacture of MTR fuel elements using $U^{233}$ must be 14 days if the $U^{232}$ content is 30–40 ppm assuming complete cleanup by ion exchange prior to metal reduction. If fuels containing higher $U^{232}$ contents are processed, it will be necessary to shorten the time schedules accordingly, or go to remote or semiremote fabrication.

* * *

*This paper is based on material presented recently at a thorium-$U^{233}$ conference sponsored by the Atomic Energy Commission at Brookhaven National Laboratory. The author was coordinator. About 60 technical papers were presented. Among the speakers and session chairmen were Clark Goodman, then of the AEC, F. T. Miles of BNL, W. C. Redman and J. Schumar of Argonne National Laboratory, O. R. Magoteaux of National Lead Co., and R. N. Lyon, E. D. Arnold and F. R. Bruce of Oak Ridge National Laboratory.*

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## Natural Uranium

*Continued from p. 88*

for the breeders to show the way to perhaps as high as 30% utilization. The breeder is a most difficult reactor and whether or not, in spite of its potential, it can achieve economies is uncertain at best. There may well be room for both converters and breeders in the ultimate nuclear complex.

There is a growing realization that designers must begin to pay more attention to fuel costs since capital costs of nuclear plants do not appear likely to come down to the range of fossil-fueled plants. It is generally conceded that the natural-U or near-natural-U systems offer the best immediate solution to reduction of fuel costs. For example, the natural-U plant indicated in the table is capable of fuel costs of 2–3 mills/kwhr with existing fuel-fabrication technology by the simple device of disposing of burned fuel without processing and without taking Pu credit. Heavy-water costs, including 1% loss, might amount to about 0.5 mills/kwh. Later on, reduced fabrication costs and Pu recycle may permit further reductions.

### Prospects

There are obvious uncertainties associated with the natural-U heavy-water systems. The chief concern lies in the area of available reactivity. Calculations indicate that 3,000–10,000 Mwd/ton brackets the range of uncertainty. Serious experiments to narrow this range are just now under way.

The cost of heavy water is high compared to ordinary water. Although initial inventory charges are well within reason, inventory loss during operation is not now known. Heavy-water reactors tend to be larger in gross volume than, say, light-water reactors and there does exist some correlation between size and cost. The dollar or mill/kwh penalties associated with these areas cannot be assessed without building and operating experience. Judicious use of enrichment up to 0.9% may prove the optimum answer even for these systems.

The Atomic Energy Commission and the industry in general have weighed the potential of the natural-U heavy-water system against the uncertainties involved and have apparently found it worthy of support for both foreign and domestic uses.

# PLUTONIUM

THERE ARE SUFFICIENT natural reserves of fissionable $U^{235}$ to support a nuclear-power economy for perhaps the next century. However, long-term, efficient use of these reserves will require conversion of $U^{238}$ to Pu in fast-breeder power reactors. Recognizing this, programs in the U. S. are directed toward studying the properties of Pu and its alloys, handling and fabrication problems, and the development of prototype fuel elements.

Groups at Los Alamos, Hanford and Argonne, as well as others in Canada, England and France, have gathered considerable data and experience. Although the properties of the pure metal are far from completely known and understood, what is known precludes the use of Pu in this form as a fuel. Therefore, the emphasis in this report is on the alloys, fabrication experience, development of prototype elements and reactor concepts utilizing Pu.

## Compounds and Alloys

In the course of seeking alloys that would serve as suitable fuel materials, a number of phase diagrams have been developed in the U. S. and U. K. Although most of the results are on a preliminary basis, good agreement is found between data developed in these two countries as well as with that published by the Russians.* Figures 1 and 2 show some of the binary systems reported by Schonfeld (Los Alamos).

**Pu alloy preparation.** The usual procedure for alloy preparation—adding constituents to the solvent melt—presents several disadvantages when used for Pu alloys: Pu metal is expensive to produce and chemically reactive; an inert gas atmosphere is required; when added to a light metal, Pu may segregate due to its low melting point and high density. Runnalls (AECL) described how these disadvan-

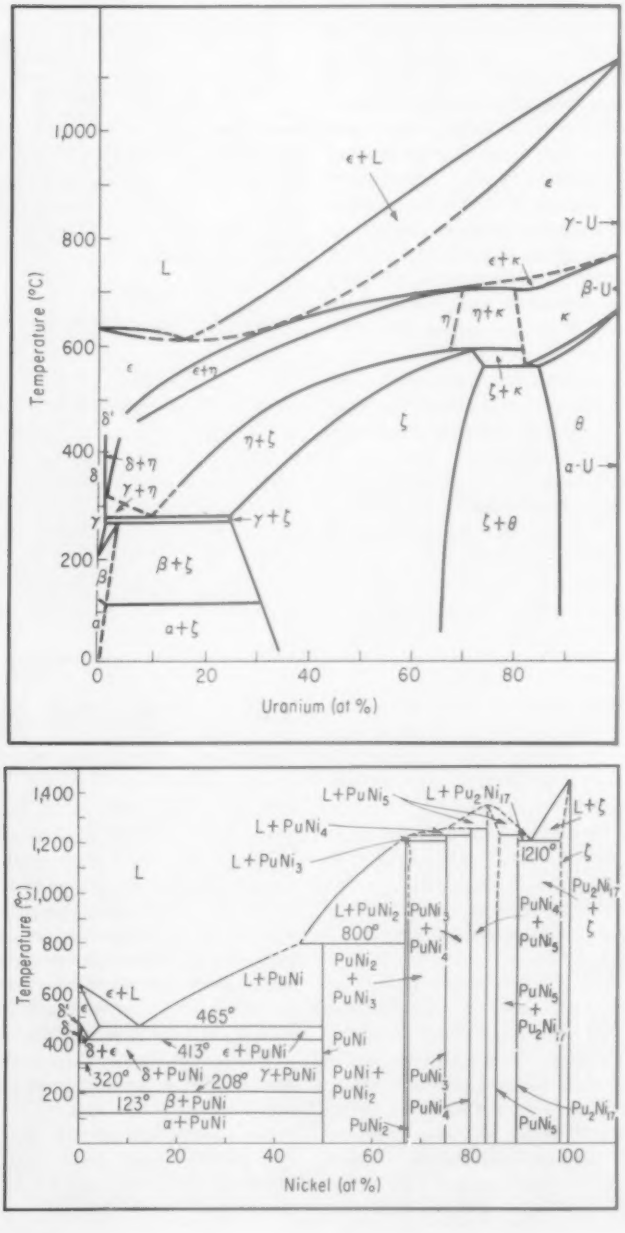



FIG. 1. Plutonium phase diagrams developed at Los Alamos (L represents liquid)

*A. S. Coffinberry, M. B. Waldron, in "Progress in Nuclear Energy, Series V, Metallurgy and Fuels," p. 403 (Pergamon Press Ltd., London, 1956).

**TABLE 1—Pu Intermetallic Compounds***

| | |
|---|---|
| >75 at% Pu | *IVA*/$Pu_{19}Zr$ *VIII*/$Pu_6Fe$, $Pu_6Co$, $Pu_{19}Ru$, $Pu_{19}Os$ *AC . . . /eta* Pu-U (30–98 atomic % Pu) |
| 60–75 at% Pu | *IIIB*/$Pu_3Al$, $Pu_3In$ *IVB*/$Pu_3Si$, $Pu_3Si_2$(?), $Pu_3Si_2$(?), $Pu_3Ge_2$(?), $Pu_3Ge_2$(?) *VIII*/$Pu_3Co$, $Pu_3Co$, $Pu_3Os$, $Pu_3Os$ *AC . . . /*$Pu_2Th$, zeta Pu-U (26–75 atomic % Pu) |
| Pu-X | *IIIB*/PuAl(?) *IVB*/PuC, PuSi *VB*/PuN, PuP, PuAs, PuBi *VIB*/PuO, PuS, PuTe *VIII*/PuNi, PuRu |
| $Pu_2X_3$ | *IVB*/$Pu_2C_3$, $Pu_2Si_3$, $Pu_2Ge_3$ *VIB*/$Pu_2S_3$, $Pu_2O_3$ (2 crystal forms) |
| $PuX_2$ | *IA*/$PuH_2$ *IB*/$PuCu_2$ *IIA*/$PuMg_2$ *IIIB*/$PuAl_2$ *IVB*/$PuSi_2$, $PuGe_2$ *VB*/$PuBi_2$(?) *VIB*/$PuO_2$ *VIIB*/$PuMn_2$,$PuRe_2$ *VIII*/$PuFe_2$, $PuCo_2$, $PuNi_2$, $PuRu_2$, $PuOs_2$ |
| $PuX_3$ | *IA*/$PuH_3$ *IIA*/$PuMg_{2-3}$ *IB*/$PuCu_3$(?), $PuAg_3$ *IIB*/$PuHg_3$ *IIIB*/$PuAl_3$ *IVB*/$PuGe_3$, $PuSn_3$, $PuPb_3$ *VIII*/$PuCo_3$, $PuNi_3$ |
| <25 at% Pu | *IIA*/$PuBe_{13}$ *IIB*/$PuHg_4$ *IIIB*/$PuAl_4$ *VIII*/$PuNi_4$, $PuNi_5$, $Pu_2Ni_{17}$, $Pu_2Co_{17}$ |

* Arranged according to periodic table groups. (?) indicates uncertainty of composition

tages can be avoided by reducing $PuO_2$ or $PuF_3$ with the solvent metal to produce alloys. The following remarks apply to several alloy preparations studied.

Aluminum reduction of $PuF_3$ was five times faster at 900° C than at 1,125° C owing to evolution of highly volatile aluminum monofluoride at 900° C; above 1,000° C, $AlF_3$ is evolved. In experiments using 60-gm Pu charges, Pu yields averaged 98%. Yields above 99% were obtained by reducing $PuO_2$ with aluminum in the presence of cryolite at 1,200° C; the aluminum oxide product was dissolved in the liquid cryolite.

$PuF_3$ was completely reduced by gallium when heated in vacuum for 2 hr at 1,150° C. It was not reduced by indium or thallium.

Pu-Be alloys have been prepared by reducing $PuF_3$ and $PuO_2$ in vacuum with beryllium. $PuF_3$ reaction was complete with high yield after 25 min at 1,125° C. The $PuO_2$ reaction was complete after 30 min at 850° C.

Silicon reduction of $PuF_3$ at 1,300° C in vacuum formed fluoride-free Pu-Si alloys in 15 min.

**Intermetallic compounds.** About 70 intermetallic compounds of plutonium have been identified through work done at Los Alamos, Chalk River, Harwell and in Russia. "Intermetallic compound" is used to include the hydrides and compounds with the metalloid elements. The crystal structures of about ⅔ of the compounds have been identified.

These compounds were reviewed by Ellinger (Los Alamos). Table 1 arranges the compounds according to the groupings of the periodic table. The A subgroup elements do not form many compounds with Pu; the group VIII elements and those of the B subgroup form the most. This also seems to be characteristic of intermetallic compounds of Th and of U with other elements.

**Burnup effects.** At Harwell, reactor-irradiation effects on Pu-containing alloys have been studied, as reported by Pugh. Results are given in Table 2.

In U-Pu alloys containing 7.5 at% Pu, the structure at 500° C was $\alpha$ U and that at 700° C was $\beta$ U. Greater distortion and cracking at 700° C can be attributed to the poorer mechanical properties of $\beta$ U and to cycling through the phase change. Segregation of Pu may account for the poor behavior of alloys containing 10 at% Pu.

For the U-Mo-6½-at% Pu alloy, performance at 700° C was better than at 500° C, probably due to a decrease in brittleness as the temperature was raised. It would appear that these alloys could be improved by reducing the Pu or Mo content to decrease the brittleness.

The Th alloys appear to behave well at 500° C.

Zirconium appears to be an excellent though expensive diluent for Pu.

## Pu Fuel Development

The first reactor to use Pu as fuel was Clementine, a Los Alamos mercury-cooled research reactor. It operated successfully until 1953, when it was dismantled. There are now no Pu-fueled reactors operating. However, development work is being done on several

**TABLE 2—Pu Fuel Burnup Compared with U**

| *Composition* | *Temperature (°C)* | *Burnup of all atoms* | *Volume increase (%)* | *R value** | *Appearance after irradiation* |
|---|---|---|---|---|---|
| U unalloyed | 500 | 0.26 | 10.2§ | 34§ | Good |
| U unalloyed | 700 | 0.27 | 11.5 | 33 | Good |
| U + 7½ at% Pu | 500 | 0.33 | 9.7 | 17 | Good |
| U + 7½ at% Pu | 700 | 0.32 | 14 | 28 | Small crack |
| U + 10 at% Pu | 400 | 0.29 | 18.3 | 53¶ | Distortion |
| U + 10 at% Pu | 700† | 0.29 | 25.4¶ | 70¶ | Large crack |
| U + 28 at% Mo | 500 | 0.50 | 3.5 | 6 | Very good |
| U + 28 at% Mo | 700 | 0.47 | 1.6 | 4 | Very good |
| U + 28 at% Mo + 6½ at% Pu | 500 | 0.22 | 11.2¶ | 45¶ | Cracked |
| U + 28 at% Mo + 6½ at% Pu | 700 | 0.22 | 2.7 | 12 | Good |
| U + 28 at% Mo + 18 at% Pu | 500 | 0.44 | | | Bulge on side |
| U + 28 at% Mo + 18 at% Pu | 700 | 0.42 | | | Cracked and distorted |
| Th + 47 at% U | 500 | 0.62 | 9.2 | 13.6 | Good |
| Th + 15 at% Pu | 500 | 0.54 | 14.0 | 22 | Good |
| Th + 47 at% U arc melt + cast | 800‡ | 0.56 | 20.4 | 30.0 | Good |
| Zr + 20 at% U | 500 | 0.20 | 1.8 | 8.5 | Very good |
| Zr + 40 at% Pu | 500 | 0.83 | 5.4 | 6 | Good |

* R value = $\frac{\%\text{ decrease in density}}{\%\text{ burnup of all atoms}}$

† For forty days, then 150 days at 315° C.

‡ After 0.3% burnup the furnace failed; the specimen then ran at 450° C.

§ Mean of three specimens.

¶ Estimated from change in dimensions.

concepts, and several Pu-fueled experimental and test reactors are under construction. Pu elements have also been tested in reactors such as the MTR and NRX.

A concept being studied at KAPL involves mixed Pu and U oxides. A liquid-metal concept under investigation at Brookhaven might utilize Pu in bismuth. Atomic Power Development Associates is interested in a "paste" reactor utilizing a fluid bed of settled or near-settled Pu particles in liquid sodium.

Three Pu-fueled reactors are scheduled for startup in 1960: Experimental Breeder Reactor-2 (EBR-2, National Reactor Testing Station, Idaho), Plutonium Recycle Test Reactor (Hanford) and the Los Alamos Molten Plutonium Reactor Experiment-1 (LAMPRE-1, Los Alamos).

The following sections give results obtained in work related to some of these projects.

## Pu-Fissium Alloy for EBR-2

Pyrometallurgical reprocessing, to be used for the EBR-2 fuel cycle, leaves some of the fission products in the reprocessed fuel to produce what is called a fissium alloy. Fissium has been found to improve the irradiation and thermal stability and corrosion resistance of U-Pu alloys.

The EBR-2 is a prototype fast-breeder power reactor. It is sodium-cooled and has a fuel element designed for high thermal performance and high burnup. Long, thin fuel pins fit loosely into a thin-walled tube with a liquid-sodium thermal bond. The initial fuel will be 49%-enriched U. Subsequently, after sufficient development, a Pu fuel will be used. An alloy of U-20 wt% Pu-10 wt% fissium with 15–20 wt% $U^{235}$ added is now being considered. An ultimate full-scale reactor, because of its larger core size, would use an alloy containing <20 wt% $Pu^{239}$ and no $U^{235}$.

A Pu fuel element for EBR-2 is now under development at ANL. The results of metallurgical studies (presented by Kelman and Dunworth of ANL) are reviewed here.

**Metallurgical requirements.** The major metallurgical requirements of the fuel are dimensional stability under irradiation, feasibility of fabrication and handling, positive and reliable thermal expansion and resistance to attack by NaK and Na. The goal is at least 2% burnup of the total atoms.

**Refining requirements.** Fission-product elements not removed by pyrometallurgical refining will determine to a considerable degree the fuel-alloy composition. The composition of a fissium-alloy for a Pu fuel will differ from that for a $U^{235}$ fuel because of the different Pu fission-yield curve. The reactor will be started up with an artificial equilibrium fissium alloy to avoid compositional changes that would occur with reactor cycling.

**Fuel-alloy studies.** The metallurgical properties can be expected to more closely resemble those of U than Pu.

The binary U-Pu phase diagram is shown in Fig. 1. Plutonium lowers the melting point and transformation temperatures of U, and low-Pu binary alloys are extremely susceptible to irradiation damage. Fortunately, the major fission-product elements remaining in the equilibrium fissium alloy improve the irradiation stability.

**Irradiation stability.** Three cast-alloy compositions were irradiated. Growth and volume changes of the irradiated samples were so small for the three sets of specimens as to make the differences between them meaningless.

**Thermal-cycling stability.** Cast as well as extruded U-20 wt% Pu-5.4 (and 10.8) wt% fissium were practically unchanged after 200 cycles between 25° C and 500° C. In contrast, U-Pu alloy pins spall and crack badly in less than 200 such cycles.

**Corrosion.** The EBR-2 fuel pin must be compatible with the environment in the reprocessing cell as well as with the liquid sodium bond within the jacket. Even in the pure helium atmosphere of the ANL glovebox facility, binary U-Pu alloys containing 20–30 wt% Pu tend to disintegrate to a powder and are pyrophoric. Fissium elements solve this pyrophoricity problem. Fissium alloys have been stored for long periods without the slightest tendency to disintegrate.

Any tendency of the alloy to dissolve in clean NaK or sodium is negligible. This has been borne out even under long-term irradiations at elevated temperatures. However, small amounts of oxygen in the liquid metal cause weight changes in the alloy, and large amounts cause spalling and cracking.

**Fabrication.** In the EBR-2 reprocessing cycle, the pin-fabrication technique requires only that the alloy be castable and possess sufficient strength and ductility to allow mold stripping and subsequent handling operations.

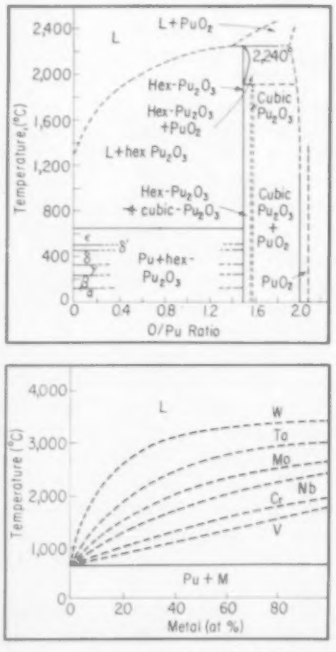
The fissium alloys can be readily gravity-cast into molds or injection-cast into Vycor tubes. The solidus of U-20 wt% Pu-10 wt% fissium is 930° C.

Attempts to hot-roll U-Pu-fissium alloys failed even at 800° C. The fissium alloys are harder than U and more difficult to machine. Carbide-tipped tools and slow machining speeds are essential.

**Thermal expansion and density.** The as-cast U-Pu-fissium alloys behave dilatometrically about the same as cast, unalloyed U. Over the range 20–100° C, the U-20 wt% Pu-10.8 wt% fissium alloy has a thermal expansion coefficient of $12.4 \times 10^{-6}$ per ° C. Its density is 16.6 gm/cm³.

**Thermal conductivity.** The heat-transfer performance of EBR-2 must far exceed normal engineering practice. Therefore, the poor thermal conductivity of the alloys is cause for concern. Addition of 10 wt% Pu lowers the conductivity of U, and fissium is expected to lower it further. However, the conductivity of the U-5 wt% fissium alloy

**FIG. 2. Plutonium phase diagrams developed at Los Alamos (L represents liquid phase)**



increases more rapidly with temperature than does that of U, so that the difference is small at reactor operating temperatures.

## NRX Pu-Al Elements

The present NRX fuel element, described by Wanchope (Chalk River), consists of a stack of twelve Pu-Al slugs 9.022 ± 0.005 in. long and 1.360 ± 0.002 in. in diameter with aluminum end pieces loaded directly into a finned aluminum sheath 1.410 in. i.d. and 0.080 in. thick. The end pieces are drilled deeper than the threading to provide a helium reservoir.

The bare alloy slugs required new fabrication techniques. $PuO_2$ is reduced with aluminum in the presence of cryolite and sufficient excess aluminum to produce the desired alloy. A separate reduction is performed for each slug—28 gm of Pu and 758 gm of Al are used to yield a 3.7% alloy. About 200 mg of Pu are lost to the slag and crucible.

The reduction billets are induction-melted in graphite crucibles in air. The 765-gm castings are 12 in. long and 1.41 in. in diameter with 2½ in. of pipe. They contain ~27.2 gm of Pu, about 2% being lost as oxide. Pu concentration varies about 5% from top to bottom of casting because of longitudinal segregation. Inverse segregation of Pu at the casting surface has been noted.

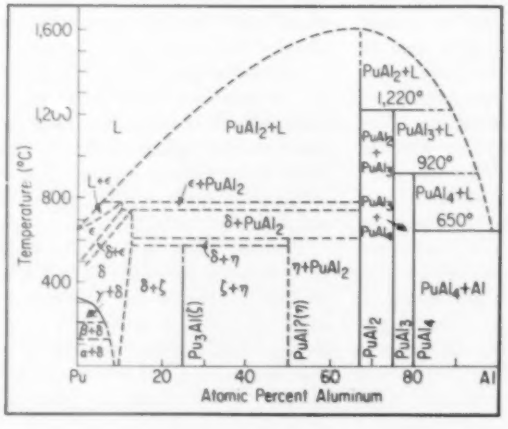
The cast slugs are machined to a diameter of 1.360 ± 0.002 in. The surface is free of visible porosity. The piped ends are cut off, and the slugs are finished to a length of 0.022 ± 0.005 in. The finished slugs weigh 595 ± 1.0 gm and contain ~21.7 gm of Pu. About 3.5 gm of Pu is contained in the piped end and 2 gm in the machine cuttings.

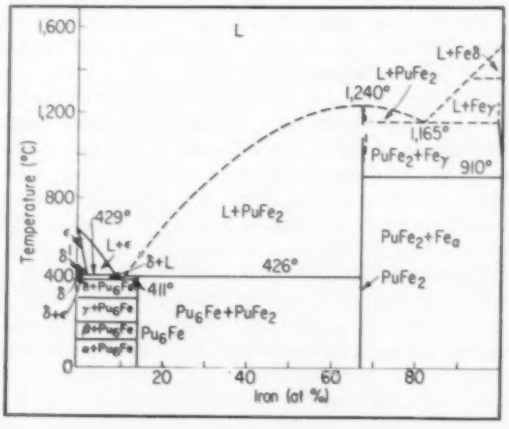
The Pu yield from initial nitrate solution to finished slug averages 77%. The 13% in the piped end is recovered by remelting. The 7% contained in lathe cuttings and 2% in melting drosses is recovered by chemical processing. The remaining 1%, dusting and reduction losses, is not considered to be economically recoverable waste.

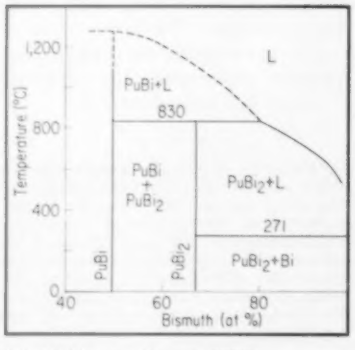
**Element assembly.** One end of the finned sheath is welded closed. The end pieces and slugs are inserted in the sheath in a fume hood. The assembly is then evacuated, held at 160° C for 4 hr and cooled under vacuum to remove adsorbed water. The assembly is then drawn through a die to bring the sheath into close contact with the slugs.

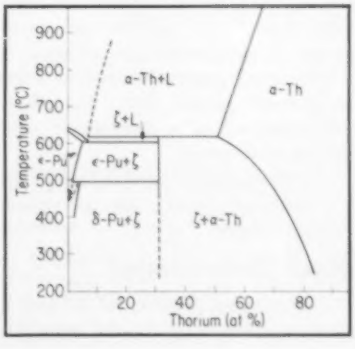
The ends of the sheath are cut off and faced off, leaving 3/16 in. protruding beyond each end piece. This metal is spun down over the end pieces. The outer end pieces are screwed into place and welded. Weld integrity is checked by taping a polyethylene sleeve over the element, covering both welds, pressurizing the sleeve with helium and evacuating through the vents and a mass-spectrometer leak detector. The vents are then welded closed.

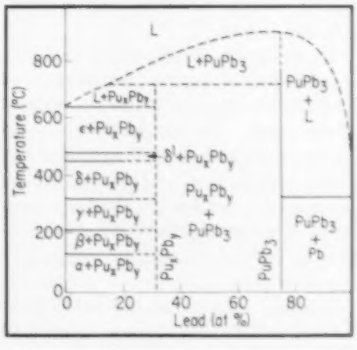
The alloy preparation, casting and machining are carried out in gloveboxes. It has proved possible to carry out all subsequent operations in fume



hoods or open machine shops without spread of contamination.

## MTR Pu-Al Elements

Plutonium has been incorporated in MTR fuel elements to study its behavior as a fuel and to produce transplutonic elements. Fabrication of clad Pu-Al fuel element billets, was described by Tate (Los Alamos).

The design of the Pu-Al MTR billet is similar to the MTR U-Al billet sandwich, i.e., the sandwich "meat" is the Pu-Al plate in an Al frame and the "bread" is two Al cover plates. Fundamental fabrication steps are not altered by the presence of Pu, but the casting technique differs and techniques for handling the bare alloy are considerably more exacting. The core alloy is Al-10 wt% Pu.

**Alloying and casting.** A 650-gm vacuum furnace charge is prepared from ¼-in.-dia. aluminum rods and freshly machined Pu rod. Machined Pu rod minimizes spread of contamination and avoids introducing oxide impurities. Melting and alloying is carried out in a magnesia crucible.

The cast ingot has the dimensions $\frac{3}{4} \times 2\frac{1}{2} \times 6$ in. plus a sprue and weighs 550–600 gm. During ingot freezing, gravity segregation must be prevented and shrinkage minimized.

For an Al-10 wt% Pu alloy, 120 min in the furnace at 940° C is barely adequate with the existing equipment to produce a homogeneous melt. The furnace is powered by a 20-kw generator operating at 450 kc. Probably low-frequency induction heating would speed formation of a homogeneous melt. At 940° C, magnesium vapor produced through reduction of the crucible by the melt causes glow discharge. After 60 min, the violence of the discharge makes discontinuation of the run advisible. To obtain the desired 120-min melt time, the ingot is cut up, remelted for an additional 60 min and recast.

If an ingot is allowed to solidify slowly, gravity segregation occurs and much of the Pu is found in the bottom of the ingot. By using a water-cooled copper mold and controlling the rate of pour, segregation and shrinkage are minimized. An induction-heated tantalum cone around the conical crucible bottom prevents premature clogging of the pour hole.

**Rolling.** Ingots are hot-rolled from 0.75 in. to 0.45 in. with reductions of 50 mils per pass and then cold-rolled to 0.370 in. with reductions of 5–10 mils per pass.

Rolling is performed in gloveboxes. The alloy is quite resistant to oxidation and can be heated and rolled in an air atmosphere. The ingots are hot-rolled from an air furnace operating at 550° C; the hollow rolls of the mill are heated to 250° C by a circulating hot fluid.

**Blanking.** Cores $2.10 \times 2.19$ in. are blanked from the rolled stock using a conventional punch and die. This is done on a hydraulic press having a plastic and aluminum enclosure that moves up and down with the press stroke. Items are removed from the enclosure in a plastic bag by a sealing and cutting-off technique.

**Billet assembly.** The evacuation tubes are pickled in an acid bath. All interior surfaces of plates and frames are wire-brushed. The Pu-alloy cores are pickled in a nitric-hydrofluoric acid bath, rinsed in boiling water and air-dried—this permits assembling the billets in an open-front hood without spreading contamination.

In assembling, the core is pressed into the core plate. Annealing the aluminum core plate until it is dead soft and hardening the alloy core by cold-rolling eliminates the formation of a ridge of flash around the periphery of the core during press fitting. The filled core plate is combined with the remaining parts of the billet assembly, which is clamped for welding.

**Welding.** The billet is preheated with a gas torch. The periphery of the billet is then welded by an inert-arc process. The billet temperature is ~300° C during welding. Welding at this temperature is not hazardous since the oxidation rate of the Pu-Al alloy is only $3 \times 10^{-4}$ in./week at 400° C in pure oxygen, and no airborne oxide is formed.

**Evacuation and sealing.** The welded billets are evacuated and helium leak-tested. They are then evacuated against the temperature at which they will be rolled, and the evacuation tubes are pressure-welded shut. The billets are sealed off at a pressure of $<\frac{1}{2}$ micron of mercury.

The billets are shipped to Oak Ridge National Laboratory for fabrication into fuel plates.

## Mixed-Oxide Concept

The mixed-oxide concept utilizes a mixture (preferably a solid solution) of Pu and U oxides, probably in a ratio of 1 to 5, to provide an economic fuel cycle. Although there is a loss in breeding by using oxide rather than metal, this should be compensated for by economy in fuel preparation, irradiation and reprocessing. This fuel cycle, described by Cashin, is being studied at Knolls Atomic Power Laboratory.

The mixed oxide is irradiated in stainless steel tubing to 50% depletion of the original Pu. More than half the original amount remains at maximum burnup because of breeding. Reactor residence time is nearly 1 yr. For a 680-Mw reactor, Pu throughput is near 1.1 kg and exposures are 620 Mwd/kg.

After a 30-day cooling period, the irradiated fuel tubes are cut into short lengths and the oxide dissolved in nitric acid. Fission products are separated by a modified Purex aqueous process. Pu can be added to the resultant nitrate solution of U and Pu. Ammonia precipitation gives ammonium diuranate and hydrated Pu oxide, which are reduced in $H_2$ to give a solid solution of $PuO_2$ and $UO_2$. Significantly, this solid solution is readily soluble in nitric acid, but $PuO_2$ as a separate phase is very difficult to dissolve.

For compacting the oxide, pelletizing is a relatively complex process. The simpler method adopted is to make a paste, extrude, dry and sinter the oxide. With the emphasis on economy, 65–70% oxide density is used because it is not difficult to obtain.

Thermal tests and MTR cycling have shown some sintering and central void formation in the stainless steel capsules. This is attributed to poor thermal conductivity caused by low compact density and tolerance requirements. These effects can be avoided by a sodium bond, although it may not be necessary to do this.

The mixed-oxide concept appears feasible—no step in the process is difficult to achieve. Further work is required on irradiation, oxide settling and transient experiments on full-length (1 meter) fuel assemblies.

* * *

*This article is based on papers presented before a conference on plutonium held in Chicago, Nov. 4–5, 1957, under the auspices of the U. S. Atomic Energy Commission and the American Society for Metals. The papers are to be published by the American Society for Metals under the title "The Metal Plutonium"; A. S. Coffinberry, conference chairman, is also editor of the published papers.*

*A Nucleonics Survey*

# 1. U, Th Conversion Services of U. S. Companies

| Company →* | Am. Lava | Davison | Mallinckrodt | National Lead | NUMEC | Shattuck |
|---|---|---|---|---|---|---|
| U processed to date (lb) | | | | | | |
| Natural | Starting operation in '58 | Not released | 20–25,000 | Ton lots | 761 | 200,000 (since 1928) |
| Enriched | | 1,200 | 125,000 | Ton lots | 582 | |
| Types of research and development | Nuclear ceramics | Feed and raw materials | $UF_6$ conversion; $UO_2$ ceramics fabrication | Fuel-element fabrication; metallurgical process development | Chemistry, metallurgy, ceramics for fuel, control, cladding, moderating materials | Th and U ore refining; production of chemicals |
| Guaranteed conversion yields | | 100% with losses included in price; otherwise 96–99% | 98–99% | 98–99% | 98–99% | 95% minimum |
| Materials offered—enrichments, annual output capacity (lb) | | | | | | |
| Uranium, metallic | | | Pickled reduction buttons | | | |
| Ingot | | All enrichments | | Yes, tons | All enrich.; | |
| Rods | | All enrichments | | Yes, tons | 100,000 | |
| Plates | | All enrichments | | Yes, tons | | |
| Uranium oxide | | | | | | |
| Pellets | Yes | Yes | Yes Capacity depends on | Yes, tons | All enrich.; 100,000 | |
| Ceramic grade | Yes | Yes | Yes enrich. Also uranyl | Yes, tons | All enrich.; 100,000 | 25,000 |
| Dispersion grade | Yes | Yes | Yes sulfate, nitrate, | Yes, tons | All enrich.; 100,000 | 25,000 |
| Uranium alloys | Also graphite-clad $UO_2$, $UC_2$ | Nb, Mo, Th, Zr | fluoride; UC; UN, $UF_4$; $U_3O_8$; ammonium diuranate | | All enrichments Uranium sulfate | $U_3O_8$; $UO_2$; uranyl acetate, chloride, formate, nitrate, sulfate, etc. |
| Thorium, metallic | | | | | | |
| Ingots | | Yes | | Yes, tons | 100,000 | |
| Rods | | Yes | Licensed for | Yes, tons | | |
| Plates | | Yes | handling Th—under develop- | Yes, tons | | |
| Thorium oxide | | | ment | | | |
| Pellets | Yes | Yes | | Yes, tons | 50,000 | |
| Ceramic grade | Yes | Yes | | Yes, tons | 50,000 | |
| Dispersion grade | Yes | Yes | | Yes, tons | 50,000 | |
| Thorium alloys | Also graphite-clad $ThO_2$ | Nb, U, Al, Mg | | | 100,000 | |
| Fabrication facilities | Ceramic materials plant; assembly, cladding or canning of pellets | Convert concentrates or hi-grade U and Th ores to metal or oxide; convert U of all enrichments to metal or oxide | Hi-density, hi-integrity ceramic shapes; equipment for loading pellets into fuel elements not yet installed | Rolling, pressing, extrusion, swaging, cladding, etc.; melting; heat treating; machining for variety of shapes | Oxide, cermet, metal-powder sintering; melting; brazing; inert-gas welding; machining | Chem. extraction, purification of U and Th raw materials |
| Test facilities | γ-spectrometry; anal. lab.; hi-temp. lab | Metallurgical chem. lab.; spectrographic isotopic analysis | Complete r & d lab. for customer problems; complete analytical facilities except mass spectrography | Isotope analysis arranged with national lab.; analytical, metallographic, nondestructive test labs. | Chem. anal.; X-ray and spectrographic analysis; U assay; corrosion testing; leak test; metallography | Chem. analysis; not isotopic analysis |
| Scrap recovery | No | All U enrichments; all common scrap materials | All assays of unirradiated scrap | All assays of unirradiated scrap | All assays of unirradiated scrap | Unirradiated nat.-U scrap |

* Am. Lava = American Lava Corp., Subsidiary of Minnesota Mining and Manufacturing Co. (Chattanooga, Tenn.); Davison = Davison Chemical Co., Division of W. R. Grace & Co. (Baltimore, Md.); Mallinckrodt = Mallinckrodt Chemical Works, Special Metals Div. (St. Louis, Mo.); National Lead = National Lead Co., Nuclear Metals Div., (New York, N. Y.); NUMEC = Nuclear Materials & Equipment Corp. (Apollo, Pa.); Shattuck = S. W. Shattuck Chemical Co. (Denver, Colo.).

**Spencer Chemical Co.,** Kansas City, Mo. (information received too late to include in table above). Processed to date: several hundred lb nat. U, <100 lb enr. U. Research and development: fuel processing. Guaranteed conversion yield: 97–99%. Products: concentrated uranyl nitrates or uranium oxides (~25 tons/yr). Scrap-recovery service: all types of fuel amenable to solvent extraction.

# 2. Fuel-Fabrication Services, Experience

| Company → | Aerojet-General Nucleonucs, San Ramon, Calif. | Atomics International, Div. of North American Aviation, Inc., Canoga, Park, Calif. | Babcock & Wilcox Co., New York 17, N. Y. | Clevite, Cleveland, Ohio | Combustion Engineering, Inc., Windsor, Conn. | Davison Chemical Co., Baltimore, Md. |
|---|---|---|---|---|---|---|
| Plant area ($ft^2$)* | 17,500 | 20,000 | 64,000 | 25,000 | 45,000 | 20,000 |
| U processed to date: | | | | | | |
| Natural (lb) | Many | 4,000 | 600 | 4,000 | Classified | Not released |
| Enriched (lb) | Several hundred | 28,000 | 32,000 | 2,000 | | |
| Fuel types equipped to make† | Ss-$UO_2$ plate; polyethylene-$UO_2$ | Flat plates, slugs, cylinders; metallurgically, liquid-metal, inert-gas bonded; metal, cermet, ceramic | Al plate, cylinder; Zr plate; oxide plate, rod | Plates, rods, tubes, natural and enriched, metal and oxide | Plate | Ceramic |
| Reactors for which fuel was supplied or contracted for (no. of elements)‡ | AGN 201—polyethylene-26wt % $UO_2$ disks, 150<br>AGN 211—poly-$UO_2$ blocks, 60<br>GCRE—ss-$UO_2$, 100 | OMRE—2 core loadings<br>SRE—2 core loadings<br>Piqua Organic Moderated Reactor<br>Sheldon Nuclear Power Station (Nebraska) | Al plate: MTR—330, ETR—1,000, ASTR—33, GTR—68, LPTR—45, 9 foreign research reactors—35–40 each; Al cylindrical: WTR—92; oxide, rod: N. S. Savannah—slightly enriched, 32, Con. Ed.—fully enriched, $UO_2$-$ThO_2$, 120; U. S. Navy cores | MTR—Al-U, 300<br>Swedish Test Reactor—Al-U MTR type, 50 | S1C, S3W, S5W—plate type, other information classified | Con. Ed. critical assembly—highly enriched $UO_2$-$ThO_2$ pellets in ss pins, 25,000 |
| Materials company can handle§ | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Al, ss, Zr | Cer, dis, Th |
| Max. U enrich. handled | 93% | 93% | 95% | 93% | 75% | Highly enriched |
| Hot cells { Testing | | Yes | | | | |
| Hot cells { Fabrication | | | | | | |
| **Fabricating Capabilities¶** | | | | | | |
| Melting facilities | | | | | | |
| Induction heating | Air, atmos, vac | Air, atmos, vac | Air, atmos, vac | Air, atmos, vac | Vac | Atmos, vac |
| Arc melting | | Atmos, vac | Atmos, vac | Atmos, vac | Atmos, vac | Atmos, vac |
| Powder metallurgy equipment (max. capacity, in.) | | | | | | |
| Cold pressing | 4″ dia. | 12″ × 12″ | 4″ × 6″ | Depends on pressure | | Yes |
| Hot pressing | $2\frac{1}{2}$″ dia. | 3″ × 12″ | | 12″ dia | | |
| Sintering | Yes | 6′ × 8″ × 8″ | 4″ × 6″ | Yes | | Yes |
| Rolling mills (max. roll dia. × face length, in.) | | | | | | |
| Hot rolling { 2-high | | 12 × 12 | 16 × $22\frac{1}{2}$ | 10 × 9, 14 × 16 | 16 dia × 18 | |
| Hot rolling { 4-high | | | $22\frac{1}{2}$ backup, $6\frac{1}{2}$ work | 5 × 8 backup | | |
| Cold rolling { 2-high | | 12 × 12 | 16 × $22\frac{1}{2}$ | 10 × 9, 14 × 16 | 16 dia × 24 | |
| Cold rolling { 4-high | | | $22\frac{1}{2}$ backup, $6\frac{1}{2}$ work | 5 × 8 backup | | |
| Extrusion press (max. tons) | | | | 500 | | |
| Swaging equipment (max. dia.) | | 1 | $2\frac{3}{4}$ | $1\frac{1}{8}$ | | |
| Drawing equip. (max. pull, lb) | | | 2,000 | | | |
| Milling (max. capacity, in.) | Several | 96 bed | 20 × 5 | 28 | 96 travel cap. | |
| Lathes (max. capacity, in.) | 52 dia × 72 | 18 | 18 dia × 84 | 12 dia × 72 | 18.5 dia | Yes |
| Vacuum annealing | | Yes | Yes | Yes | Yes | |
| Inert-atmos. furnaces | Yes | Yes | Yes | Yes | | |
| Inspection equipment | | | | | | |
| X-radiography (max. kv) | 255 | 250 | 1,000 | 250 | 300 | |
| Fluoroscopy | | | Yes | 150 | | |
| Ultrasonic | Yes | | Yes | | Yes | |
| Eddy current | | Yes | Yes | | Yes | |
| Dye penetration | Yes | Yes | Yes | Yes | Yes | |
| Autoclaves | | Yes | Yes | Yes | Yes | |

NOTE: All companies, with the exception of Norton, provide research and development services.

All companies, with the exception of Nuclear Development Corp., fabricate fuel on a production basis; Nuclear Development provides only research and development.

* Plant area is restricted to area devoted to fabrication.

† Abbreviations: ss = stainless steel, enr. = enriched, Zry = Zircaloy.

‡ Reactor abbreviations: AGN 201 and 211 = Aerojet-General Nucleonics research reactors; ASTR = Aircraft Shielding Test Reactor; BR-3 = Belgian Reactor-3; Con. Ed. = Consolidated Edison (Indian Point); EBR = Experimental Breeder Reactor; ETR = Engineering Test Reactor; Fermi = Enrico Fermi Fast Breeder Reactor; GCRE = Gas-Cooled Reactor Experiment; GETR = General Electric Test Reactor; GTR = Ground Test Reactor; LMFR = Liquid Metal Fueled Reactor; LPTR = Low Power Test Reactor; MTR = Materials Testing Reactor; OMRE = Organic Moderated Reactor Experi-

# and Capabilities of U. S. Companies

| General Atomic, Div. of General Dynamics Corp., San Diego, Calif. | General Electric Co., Atomic Power Equipment Dept., San Jose, Calif. | Gulton Industries, Inc., Metuchen, N. J. | D. E. Makepeace Div., Engelhard Industries, Inc., Attleboro, Mass. | Martin Co., Baltimore Md. | M & C Nuclear, Inc., Attleboro, Mass. | National Lead Co., New York, N. Y. |
|---|---|---|---|---|---|---|
| 12,000 | 100,000 | | 30,000 | 50,000 | 136,506 | 50,000 |
| 50 kg<br>63 kg (20% enr.)<br>Rod, plate | Rod, plate | $UO_2$ pellets | 20,000<br>5,000<br>Al, Zircaloy, Nb base alloys; dispersions | 264<br>293<br>Tube, plate, rod; alloy, ceramic, cermet | 37,000<br>11,266<br>Clad, unclad wire, rod, tube, foil, plate, slab, disk; nat. and enr. U, Th; alloys; cermets with Al, ss, Zr | Nat. and enr. metal, alloy, or oxide; Zr, Al, ss clad |
| TRIGA reactors —U-ZrH, Al sheath | Plate type: includes Lockheed, Spain, Venezuela, GETR; rod type: includes VBWR (2nd load), Dresden, PG&E | | LMFR critical assembly<br>BNL critical assembly<br>Fermi—pins, Zr-clad, U-10wt% Mo, 15,000 (under contract with Nuclear Metals) | Martin Power Reactor—tube, ss-clad ss-$UO_2$, 2,126; U. S. Army Critical Experiment—plate, ss-clad enriched-U foil, 1,300<br>SPERT-2—MTR type, U-Al, 1,322<br>Penn. State Reactor—concentric tube, plastic-clad ss-$UO_2$, 4 assemblies | $UO_2$-ss: VBWR—plate, 1,000; SPERT-3—76 assemblies; $UO_2$ pellets in ss tubes<br>U-Al: Battelle reactor—28 assemblies; BORAX-3—plate, 3,000<br>U-ZR: KAPL—PT type, 2,000<br>U, Th: wire, rod, tube, foil, etc.<br>Participated in S1G, S2G, S3G, S5W, etc. | |
| Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Cer | Al, dis, ss, Zr | Al, cer, dis, ss, Zr | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr |
| 20%<br>Yes | Fully enrich.<br>Yes<br>Yes | 2% | 93% | 93% | Any | 30%<br>Yes<br>Yes |
| Air, atmos, vac<br>Atmos, vac | Air, atmos, vac<br>Vac | | Air, atmos, vac<br>Atmos, vac | Air, atmos, vac<br>Atmos, vac | Air, atmos, vac<br>Atmos, vac | Air, atmos, vac<br>Atmos, vac |
| Yes | Yes | 2" | 3" × 6" | 3" | 15 $in^2$ $UO_2$-ss | No limit |
| Yes<br>Yes | Yes<br>Yes | 6" | 8" × 8" × 96" | 3"<br>24" hot zone | 20 $in^2$-$UO_2$-Al<br>18" × 120" | Yes<br>Yes |
| 8 × 10<br>2½ × 10 | Depends on material<br>Yes | | 10 × 30 | 10 × 8<br>8 × 8 | 20 dia × 20 | 18<br>22 |
| 8 × 10<br>2½ × 10 | Yes<br>Yes | | 9 × 12<br>3 × 7 | 10 × 8<br>8 × 8, 2 × 8 | 20 dia × 30<br>5½–6 dia × 18 | |
| 500 | Yes | | Yes | | 550 | 1,200 |
| 1¾ tube | Yes | | 3 | 1 | 3 | 1½ |
| 20,000 | | | 185,000 | 25,000 | 1,000 | |
| Yes | Yes | Yes | 62 | 30 | 24 × 144 | Yes |
| Yes | Yes | Yes | 16 | 72 | 16 dia × 126 | Yes |
| Yes<br>Yes | Yes<br>Yes | Yes | Yes<br>Yes | Yes<br>Yes | Yes<br>Yes | Yes<br>Yes |
| | Yes | | Yes | 250 | 300 | Yes |
| | | | Yes | Yes | Yes | |
| | Yes<br>Yes | Yes<br>Yes | Yes | Yes<br>Yes | Yes<br>Yes | Yes<br>Yes |
| Yes<br>Yes | Yes<br>Yes | | Yes<br>Yes | Yes<br>Yes | Yes<br>Yes | Yes |

ment; SGR = Sodium Graphite Reactor; SPERT-3 = Special Power Excursion Reactor Test-3; S1C, S1W, S3W, S5W, S1G, S2G, S3G = submarine propulsion reactors; SRE = Sodium Reactor Experiment; TRIGA = Training, Research and Isotope Production-General Atomic; VBWR = Vallecitos Boiling Water Reactor; WTR = Westinghouse Test Reactor.

Other abbreviations: AEC = U. S. Atomic Energy Commission, BNL = Brookhaven National Lab., KAPL = Knolls Atomic Power Lab., PG & E = Pacific Gas & Electric Co.

‡ Cer = ceramics, dis = dispersions, ss = stainless steel.

¶ "Yes" indicates that a company has equipment of this type.

**Melting.** Atmos = atmosphere, vac = vacuum.

**Drill presses.** All companies have these presses except Norton.

**Joining equipment.** All companies have inert-arc welding except Norton. All have drybox welding except Norton and Gulton. All have brazing except Norton and Davison.

# 2. U. S. Fuel Fabricators (Cont.)

| Company→ | Norton Co., Worcester, Mass. | Nuclear Development Corp. of America, White Plains, N. Y. | Nuclear Materials and Equipment Corp., Apollo, Pa. | Nuclear Metals, Inc., Cambridge, Mass. | Sylvania-Corning Nuclear Corp., Bayside, N. Y. | Westinghouse Electric Corp., Pittsburgh, Pa. |
|---|---|---|---|---|---|---|
| Plant area ($ft^2$) | 5,000 | 10,000 | 42,000 | 65,000 | 75,000 | 100,000 |
| Unprocessed to date:* | | | | | | |
| Natural (lb) | 5,000 $UO_2$ | 40 | 761 | 314,000 | Classified | 10 kg |
| Enriched (lb) | 50 kg $UO_2$ | 2 | 582 | 1,610 | | 100 kg highly enr.<br>10,000 lb (2–5% enr.) |
| Fuel types equipped to make† | Unclad $UO_2$, $UO_2$-$ThO_2$, $UO_2$-$Al_2O_3$ | $UO_2$-ss (development) | Oxide pellets, dispersions; alloys | Rod, tube, nested tube, flat, etc.; U, U alloy clad with Zr, Zircaloy, Al, Be; cermets, clad; Al-clad Th, Th alloys | Box type, tube, special shapes; ceramic pellet; ss or Zircaloy clad ceramic; ss-$UO_2$ dispersion; Al-clad U, Th slugs | Alloys, cermets, ceramics of all types |
| Reactors for which fuel was supplied or contracted for (no. of elements)‡ | Supplied and are supplying for studies: fully enr. $UO_2$-$ThO_2$ pellets, Al clad, 1,000 kg; $UO_2$ pellets, to 1", 13,000 lb; fully enr. $UO_2$-$Al_2O_3$ strip; fused $UO_2$ for swaging; $Al_2O_3$-clad $UO_2$ pellets | NDA does only fuel element development, not production | SGR—oxide pellets, rings | EBR-1 Mark 3—rod, U-2wt%Zr Zry-2 clad, 1,900 ft<br>Exponential pile—U-Al foil, 14,000 ft<br>CP-5—nested tubes, Al-clad 26wt%U-Al, 26 assemblies<br>S1W, S1G, S3G—oval rod, Zry-clad 7–22 wt% U-Zr, 1,000<br>Fermi—pins, Zr-clad, U-10wt% Mo, 15,000 | BNL—Al, special shape, 5,000<br>Chalk River—pool type<br>AEC—Al-canned slug, amount classified<br>Others—description requires clearance<br>Fermi—pins, Zr-clad, U-10wt% Mo, 15,000 | General exptl. work<br>Yankee Atomic Electric—critical expt.; also ss-clad $UO_2$ pellets, 3% enriched, 76 elements of ~305 rods each<br>BR-3—ss-clad $UO_2$ pellets, ~4% enriched, 32 elements of ~110 rods each<br>U. S. Navy cores |
| Materials company can handle§ | Cer | Al, dis, ss | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Al, cer, dis, ss, Th, Zr | Al, cer, ss, Zr |
| Max. U enrich. handled | | 93% | 95% | 93% | 93% | 93% |
| Hot cells { Testing | | | | | | |
| Hot cells { Fabrication | | Yes | | | | Yes |
| **Fabricating Capabilities¶** | | | | | | |
| Melting facilities | | | | | | |
| Induction heating | | | Air, atmos, vac | Air, atmos vac | Air, atmos, vac | Air, atmos, vac |
| Arc melting | | | Atmos, vac | Atmos, vac | Atmos, vac | Atmos, vac |
| Powder metallurgy equipment (max. capacity, in.) | | | | | | |
| Cold pressing | | 3" × 3" | Yes | 8 dia × 24 | 7.5² | 2 sq. |
| Hot pressing | | | Yes | 8 dia × 24 | 30² | |
| Sintering | | 9" × 13" × 30" | Yes | 2¼" × 6" | Yes | 6 × 8 × 15 |
| Rolling mills (max. roll dia. × face length, in.) | | | | | | |
| Hot rolling { 2-high | | 10 × 10 | | 6 × 8 | 16 × 24 | 12 × 14 |
| Hot rolling { 4-high | | | | | 1¾ × 8 (work rolls) | 32 × 29, 15 × 24 |
| Cold rolling { 2-high | | 10 × 10 | | 6 × 8 | 16 × 24 | 10 × 10 |
| Cold rolling { 4-high | | | | | 1¾ × 8 (work rolls) | 28 × 24, 8 × 24 |
| Extrusion press (max. tons) | | | | 1,000 | 300 | |
| Swaging equipment (max. dia.) | | | | 3¾ tube, 1½ solid | 0.625 | |
| Drawing equip. (max. pull, lb) | | | | 25,000 20′ length | Yes | |
| Milling (max. capacity, in.) | | 10 × 45 | 10,000 | 24 × 10 | × 60 | 120 |
| Lathes (max. capacity, in.) | | 28 × 60 | 60 long | 24 dia × 120 | 16 dia × 84 | 26 dia × 96 |
| Vacuum annealing | | Yes | 20 dia × 80 | Yes | Yes | Yes |
| Inert-atmos. furnaces | | Yes | | Yes | Yes | Yes |
| Inspection equipment | | | Yes | | | |
| X-radiography (max. kv) | | Yes | Yes | 150 | 150 | 250 |
| Fluoroscopy | | | | Yes | Yes | Yes |
| Ultrasonic | | Yes | | Yes | Yes | Yes |
| Eddy current | | Yes | | | Yes | |
| Dye penetration | | Yes | | Yes | Yes | Yes |
| Autoclaves | | Yes | Yes | Yes | Yes | Yes |

NOTE: All companies, with the exception of Norton, provide research and development services.

All companies, with the exception of Nuclear Development Corp., fabricate fuel on a production basis; Nuclear Development provides only research and development.

* Plant area is restricted to area devoted to fabrication.

† Abbreviations: ss = stainless steel, enr. = enriched, Zry = Zircaloy.

‡ Reactor abbreviations: See previous page.

Other abbreviations: AEC = U. S. Atomic Energy Commission, BNL = Brookhaven National Lab., KAPL = Knolls Atomic Power Lab., PG & E = Pacific Gas & Electric Co.

§ Cer = ceramics, dis = dispersions, ss = stainless steel.

¶ "Yes" indicates company has equipment.

Melting. Atmos = atmosphere, vac = vacuum.

Drill presses. All companies have these presses except Norton.

Joining equipment. All companies have inert-arc welding except Norton. All have drybox welding except Norton and Gulton. All have brazing except Norton and Davison.

# MITR
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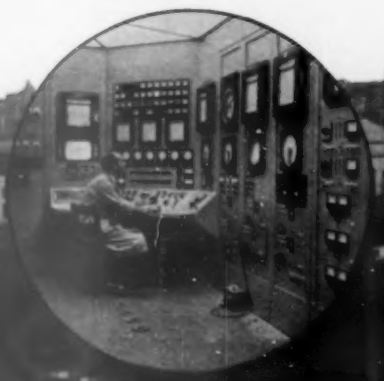
With the completion of the world's first privately owned heavy water research reactor, at the Massachusetts Institute of Technology, comes a new and powerful instrument to further man's knowledge in the peacetime use of atomic energy. As prime contractor responsible for the complete engineering design and construction of this facility, ACF Industries, Incorporated is proud to join with MIT in this achievement.

The MITR will operate at 1000KW and produce fluxes in excess of $10^{13}$n/cm²/sec. This inherently safe facility, located near the campus, includes a unique medical therapy room providing entirely new approaches to nuclear medical research techniques — a full range of experimental ports and thimbles — gamma irradiation room — chemistry hot labs — reactor control room — and equipment for servicing the reactor building.

Other ACF nuclear projects include research and test reactors under construction in Italy, Holland, Sweden and the U.S. . . . and gas cooled and boiling water power reactors being designed for the U.S. Atomic Energy Commission.



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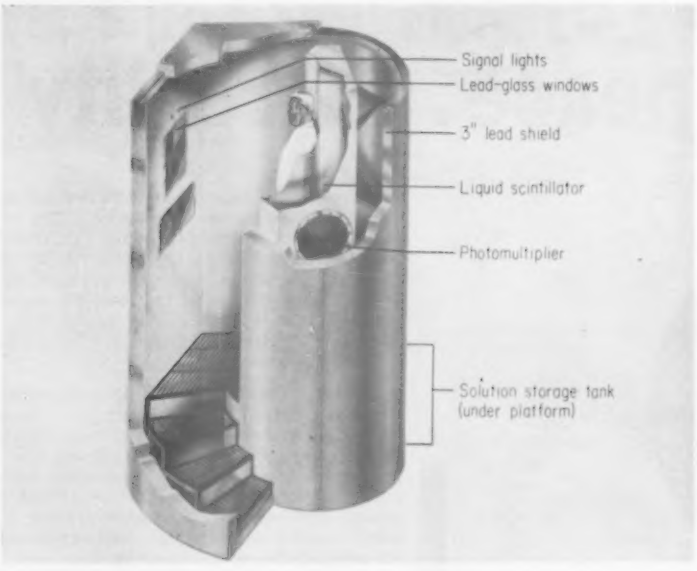



GENEVA COUNTER with subject standing in counting position. Counting "well" in which subject stands is half of an 18-in. dia cylinder

## GENEVA PREVIEW

# Walk-in Human Counter

By ERNEST C. ANDERSON, F. NEWTON HAYES and RICHARD D. HIEBERT
*Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico*

A new, greatly-improved vertical human counter has been designed for exhibit at the Second Geneva Conference. The original Los Alamos human counter—a horizontal affair designed in 1953—demonstrated the practicality of large-scale measurements of gamma radioactivity in humans and foodstuffs (NU, Jan '56, p. 27).

The Geneva counter (*at left*) is more simply constructed than its predecessor. In the Los Alamos counter, the subject lay in a sliding trough-and-sling arrangement and was inserted supine into the counter; in the Geneva counter, the subject can simply walk into the counting chamber—an arrangement far more convenient for human counting, although less satisfactory for monitoring foodstuffs. Table 1 compares the Los Alamos and the Geneva counters in detail.

The principal improvement in the Geneva counter is the use of new 16-in. photomultipliers (DuMont K-1328). In the $4\pi$ Los Alamos counter, 108 2-in. photomultipliers covered only 1.6% of the wall area, but in the $2\pi$ Geneva counter six 16-in. tubes cover 13% of the wall area with photocathodes. This also makes it possible to use triethylbenzene instead of toluene as the solvent, which reduces the fire hazard and consequently the requirements for vapor detectors and explosion-proof power circuits.

The six 16-in. diameter photomultipliers are immersed directly in the solution without windows. Should it be necessary to change a photomultiplier, the counter tank can be drained into the storage tank directly beneath the subject. A pump mounted at the rear of this tank will return the solution to the counter tank. The entire unit is mounted on a simple turntable and can be easily rotated about a vertical axis; access to the photomultipliers and to the pump is obtained by rotating the counter assembly 180 deg.

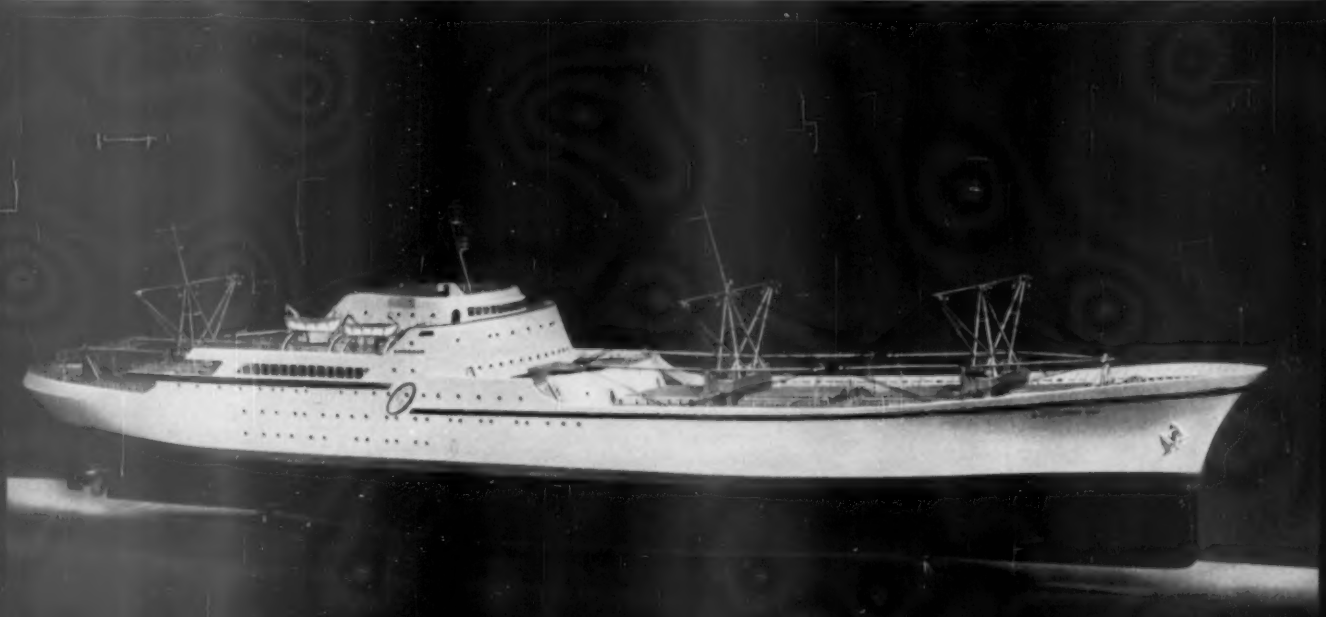
* * *

*We are indebted to R. I. Howes, W. H. Barkenhagen, and R. L. Schuch for engineering design. J. R. Gilland designed and built the transistorized electronics. J. D. Perrings and V. N. Kerr assisted in assembly and testing.*

TABLE 1—Old and New Human Counters Compared

| | *Los Alamos counter* | *Geneva counter* |
|---|---|---|
| Type | Horizontal, $4\pi$, Trough and sling | Vertical, $2\pi$, "walk-in" |
| Scintillator volume | 560 liters | 280 liters |
| Scintillator solution | Terphenyl-POPOP in toluene | Terphenyl-POPOP in triethylbenzene |
| Shielding (lead) | 20 tons | 10 tons |
| Photomultipliers | 108 2-in. (DuMont 6292) | 6 16-in. (DuMont K-1328) |
| Ratio photocathode area to total wall area | 0.016 | 0.13 |
| Electronics | Vacuum tube, coincidence analyzers | Transistorized, single-channel analyzers |
| Power | 2,500 watts | 140 watts |
| Approximate cost | $51,000 | $32,000 |
| Background (cps) | | |
| $K^{40}$ channel | 250 | 82 |
| $Sr^{90}$ channel | — | 500 |
| Counting efficiency: (70-lb phantom) | | |
| $K^{40}$ gammas | 22% | 9.4% |
| $K^{40}$ in Cs channel | 6.3% | 3.4% |
| $Sr^{90}$ bremsstrahlung | — | 0.3% |
| Statistical precision: (100 second count on average adult) | | |
| $K^{40}$ | $\pm 0.0003$ $\mu c$ $\pm 2.9\%$ | $\pm 0.0003$ $\mu c$ $\pm 3.1\%$ |
| $Sr^{90}$ (estimated) | — | $\pm 0.03$ $\mu c$ $\pm 30$ $\mu\mu c$ Sr/gm Ca |
| Resolution $K^{40}$ (half-width at half-height) | 30% | 18% |

# *Creative Engineering by* DE LAVAL



One of the U.S. Government's exhibits at the Brussels World's Fair is the model of the first nuclear ship, the N/S SAVANNAH, shown above.

The De Laval Steam Turbine Company is proud to play an important part in the design and construction of this 22,000 shaft horsepower vessel, the keel of which was laid on May 22, 1958, Maritime Day, at the New York Shipbuilding Corp. in Camden, New Jersey.

Under the joint sponsorship of the Atomic Energy Commission and the U. S. Maritime Administration, major contributions to the design and construction of the vessel and its machinery are being made by:

- *George G. Sharp, Inc., naval architects, designers of the vessel*
- *Babcock & Wilcox Company, designers and builders of the pressurized water reactor and its accessories*
- *New York Shipbuilding Corp., Camden, N. J., builders of the vessel*
- *De Laval Steam Turbine Company, designers and builders of the main propulsion machinery, other engine room auxiliaries; coordinators of all engine room equipment.*

We are particularly happy to serve in connection with this project of international importance. De Laval has often performed other important services as complete engineering coordinators, and is fully prepared to undertake similar assignments.

DE LAVAL *Steam Turbine Company*

*Nottingham Way, Trenton 2, New Jersey*

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**MODEL FNS-3** measures by SCINTILLATION METHOD "fast" neutron flux in the presence of intense gamma radiation. Large 2" scintillator optically coupled to 6292 integrates proton-recoil induced pulses in stable electronic circuit and indicates fast neutron population on front panel meter. Neon flasher, and jack for earphones, makes FNS-3 extremely versatile for Health Physics, Beam hole measurements, and wherever accurate determinations of "fast" neutrons are required.

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- *No Gamma response in fields up to 3R*
- *Transistorized HV supply*
- *Large 4" panel meter*
- *Three wide sensitive ranges*
- *Front panel neon flasher*
- *Front panel jack*

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MOUNTAIN LAKES, N.J.


# Silicon Diodes Improve Reactor Period Meters


By **WILLIAM K. BROOKSHIER**
*Argonne National Lab., Lemont, Illinois*


Silicon diodes have permitted development of period meters that are simpler and more reliable than those made with thermionic diodes. The useful current range for the silicon diodes is displaced one decade above the range of the 9004 thermionic diode. This has helped to reduce pickup problems and shorten response time. True, the logarithmic curve of the selected silicon diode is not as good as that of the 9004, even in the middle of the useful current range, and may result in a 20% variation in the period indication due to slope variations along the curve. However, this is a minor disadvantage since the period meter is primarily a safety device rather than an accurate indicator.

A block diagram of a typical reactor period meter is shown in Fig. 1. Here, d-c current from a neutron-sensitive ion chamber is fed into a device that gives an output voltage proportional to the logarithm of the current. This output voltage is inversely proportional to the period $T$, and an appropriately calibrated meter reads $T$ directly. The input voltage drives an appropriately calibrated meter which shows the input current.

## Thermionic Diodes

Perhaps the most common device for this logarithmic conversion is a thermionic diode such as the 9004 which is used at Argonne over current ranges of $10^{-12}$–$10^{-4}$ amp. But complex filament circuitry is a big problem in the use of the 9004. Since the current-voltage relation for a thermionic diode depends greatly upon the cathode temperature, the diode filament normally requires a very well-regulated current supply. Another problem is the difficulty of filtering from the filament leads high-frequency transients that can couple into the anode circuit and cause false reactor shutdowns. Still another problem is the small output voltage signal (~0.2 volts per decade of current).

## Pentodes Are Better

Another logarithmic device for period meters is the pentode circuit developed at Harwell, England. In this circuit (Fig. 2) the grid acts the same way as the anode of a thermionic diode: For a given input current to the grid,

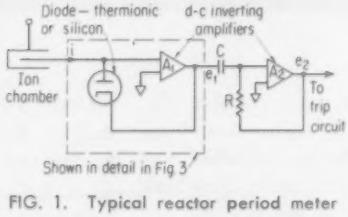


FIG. 1. Typical reactor period meter

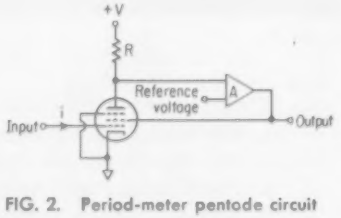


FIG. 2. Period-meter pentode circuit

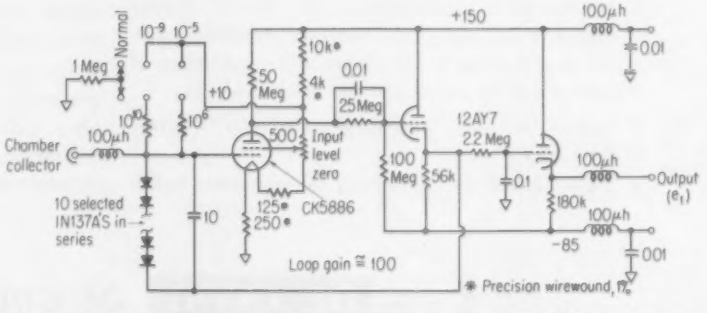


FIG. 3. Period meter circuits showing preamplifier and first amplifier. Output is amplified again (see Fig. 1) before being fed to trip circuit

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(Above) Crane lowering electrical jumper into position. Cole Connectors make contact easy, fast and positive. (Latching mechanism & supporting plates by Aeroquip)

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Another important feature of the new Cole Connector is that it can be made in any size or shape required, from miniaturized to high-capacity pins, can make any number of contacts simultaneously (thousands if necessary), yet can be manufactured economically in small numbers. It may be the solution to your connector problem. Send us your requirements and we will determine if and how it can be applied.

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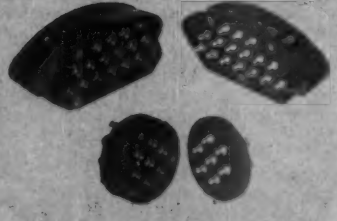
Cole Connectors are used in rectilinear manipulators for fast, easy disassembly and reassembly.



Cole Connectors can be made in any size, shape or capacity and with any number of contacts.

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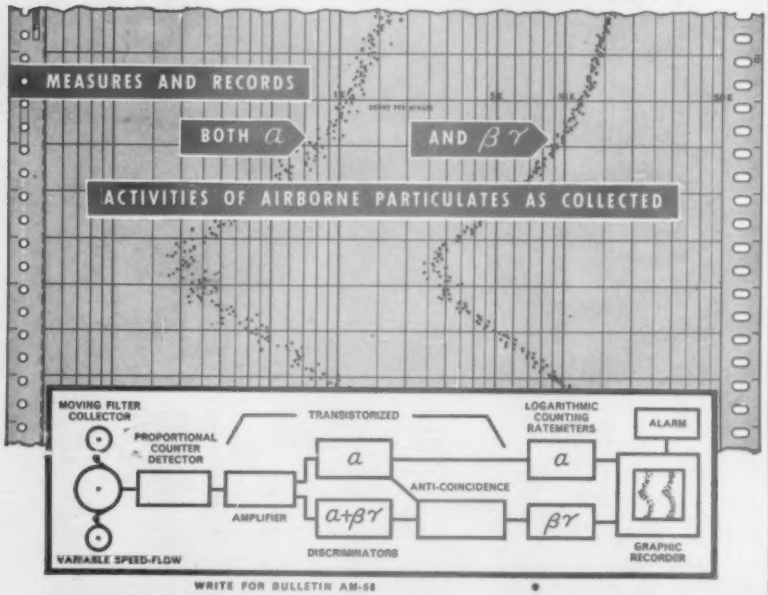


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*This article starts on page 108*

the logarithmic grid-current–grid-voltage curve determines the grid voltage. If the plate voltage deviates from a reference value, the screen voltage changes to maintain plate current constant. The voltage output signal is taken from the screen after having been amplified by the grid-screen amplification factor of the tube. For reasons not completely understood, this arrangement is much less sensitive to filament temperature variations than a simple diode. There are two disadvantages, however: The filament supply still requires some regulation, and the problem of filtering out high-frequency transients remains. The pentode's useful range appears to be 6–7 decades, depending upon tube type.

## Silicon Diodes Best

During the past two-year period ten reactor period meters have been built at Argonne with silicon diodes* in the forward-conduction region as the logarithmic device. The diagram of the input circuit (Fig. 3) shows how the silicon diodes were incorporated into the preamplifier. In each period meter a group of 10 series-connected diodes was used. The advantage here is that although the individual diode's volts-per-decade constant is only 0.08 volts, the group of 10 gives 0.8 volts per decade—four times that of a thermionic diode. Also, any number of silicon diodes can be series-connected easily, since there are no filament-isolation problems as with thermionic diodes. Another advantage is that selected silicon diodes are nearly logarithmic over 8 decades of current, $10^{-11}$ to $10^{-3}$ amps.

But silicon diodes have some disadvantages, too: Increasing their ambient temperature from room temperature to 70° C tends to displace the current-voltage curve downward along the voltage axis (Fig. 4). Although the low-current end is distorted, the rest of the curve is displaced somewhat uniformly, with the magnitude of the displacement ranging from 2–4 mv/° C. Temperature regulation was ignored in the Argonne period meters, since period meters are primarily safety devices.

Besides temperature sensitivity, one other undesirable effect was observed

* The diodes were type 1N137A by Hoffman, formerly National Semi-Conductor Products.

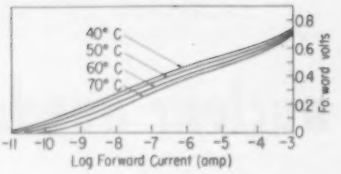


FIG. 4. Effect of temperature on current in 1N137A silicon diodes

in the silicon diodes. The shape of the current-voltage curve is influenced by the length of time that the diode has been conducting current. A curve for a diode that has passed no current for 24 hr differs from the curve for a diode that has passed 1 ma for 24 hr. Most of the displacement occurs at the low-current end and may be either above or below the original curve. The magnitude of the shift ranges from zero to a full decade of 80 mv. This displacement requires from 3–7 hr to become nearly complete, with 24 hr usually guaranteeing completion. This effect is not too important in period meters, partly because of the small percentage of diodes showing the effect, and partly because of the loose tolerances on the accuracy required.

Individual curves on over 600 1N137A's show reasonably linear semilog performance over the current range of $10^{-11}$–$10^{-3}$ amp for between 20 and 65% of the diodes in different batches. A smaller fraction, perhaps 1–10% have been logarithmic from $10^{-13}$ to $10^{-3}$ amp. The tolerances on the selection of the diodes permits slope variations of 20%.

Other than the Hoffman 1N137A's, only a few other types of silicon diodes have been investigated. Quantities of about six each of Hughes 6006's and 6552's showed very similar characteristics, but only a very small percentage covered the full 8-decade current range. About 30 Transitron 1N137's were checked without finding any diodes usable below $10^{-10}$ amp.

## TECHNICAL BRIEFS

### *Paternity Dispute*

Last year, an international team working at the Nobel Institute for Physics in Stockholm reported the discovery of a 10–12-min isotope of element 102, which they named nobelium. Recently, scientists at the University of California Radiation Laboratory at Berkeley cast doubt on the Institute results, claiming they could not duplicate them. Berkeley

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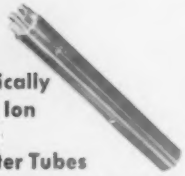

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☐ **Anton's Pancake Tubes**

Halogen quenched, sensitive beta-gamma detectors with end mica window. These units are designed for low intensity measurement and are widely used in facilities doing low-count work. Flat pancake design offers advantage of large diameter window without large volume and high background count.

Anton high efficiency tubes are Platinized*. This process provides sensitivity beyond that of standard tubes.

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☐ **229 Ratemeters**

The most precise laboratory ratemeter available, Anton's 229 Series has 7 scales, including a single log scale from 300-50,000 cpm with accuracy of better than ±2% of meter reading above ⅓ scale. It has dual range input sensitivity and provides precise and efficient measurement of radioactivity in industry, research and medicine.

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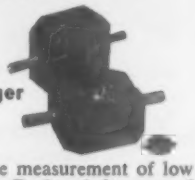

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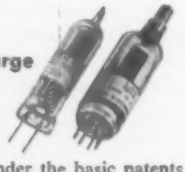

Anton is licensed under the basic patents in this field. Valuable data available concerning this low-cost solution to high voltage low current regulation problems.

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also claimed the discovery of a 3-sec-half-life isotope of the element.

The Berkeley group consisted of Albert Ghiorso, Glenn T. Seaborg and John R. Walton of the Radiation Laboratory and Torbjorn Sikkeland, an exchange scientist from Norway.

Two members of the earlier group have commented on the lack of agreement with their results at Berkeley. Paul R. Fields of the Argonne National Laboratory Chemistry Division said: "At the present time we do not have a satisfactory explanation for the fact that the Radiation Laboratory has been unable to confirm the results on element 102 that were obtained by the team of scientists working at the Nobel Institute. We plan to repeat our earlier experiments as soon as possible, probably in the early part of 1959." British scientist J. A. Milsted of Harwell said he is convinced that they had produced element 102.

**Berkeley.** The Berkeley group used their new HILAC (heavy-ion linear accelerator). A curium target ($Cm^{244}$, 4.5% $Cm^{246}$) was bombarded with 60–100-Mev carbon-12. The element-102 isotope of mass 254 was produced, which yields the daughter product fermium-250 by alpha decay. Since the 254 isotope has such a short half-life (3 sec), it was detected by observing the 30-min fermium-250.

The HILAC target was curium on a nickel foil. Element-102 recoil nuclei were slowed down in a helium atmosphere and captured on a negatively charged metallic conveyer belt. The belt passed a thin foil plate having a strong negative charge. As the 102 atoms decayed, the fermium atoms were attracted to the foil. Thus, the speed of the belt, together with the fermium-atom distribution on the foil, indicated the 3-sec half-life.

**Stockholm.** In the procedure used at the Nobel Institute, curium-244 was bombarded with 80–100-Mev carbon-13 in a cyclotron. The cyclotron target was curium on an aluminum foil. Recoil element-102 atoms were caught on organic foils. The latter were dissolved in a drop of acetone on a platinum plate, which was flamed to give a thin source for pulse analysis. The atoms were then put in hydrochloric acid solution, which was passed through an ion-exchange column. Alpha-hydroxyisobutyric acid was used to extract the element from the column.

THE INSIDE STORY

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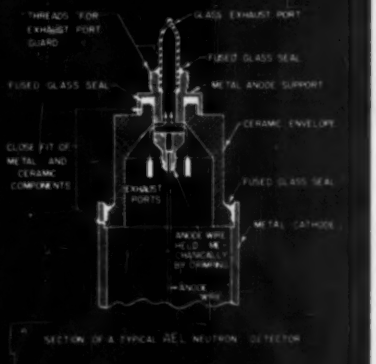

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# NUCLEAR ENGINEERING NOTES

## MTR Tries Out 20%-Enriched U

If the total power of a high-flux test reactor is to have a reasonable value, the reactor core must be kept small. Thus reactors such as the MTR have traditionally used 93%-enriched U as fuel. Recently tests* in the MTR have shown that 20%-enriched U may be just as good. This news will be of particular interest to foreign countries who would like to build high-flux test reactors and who cannot easily come by fully enriched U.

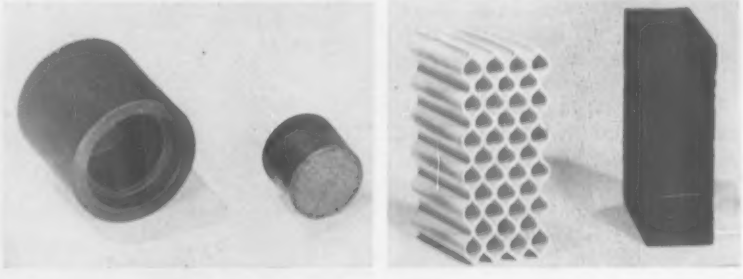
The main obstacle to using the lower enrichment was fabricating a suitable fuel element. The U-Al alloy plates had to accommodate five times as much U with no significant increase in volume and at the same time be able to withstand MTR-radiation-damage conditions. After considerable development work, Babcock & Wilcox was able to produce elements satisfying these demands. Each element has 19 plates 0.060 in. thick; the standard 93% elements had two outside plates 0.065 in. thick and 17 plates 0.050 in. thick. With the new elements, the metal-to-water ratio is increased from 0.648 to 0.770.

After reactor-physics measurements, the 20% core was run for 646 Mwd, 550 of these at the original MTR design power of 30 Mw. The new loading required 23 instead of the usual 22 fuel elements for minimum critical mass (2,063 gm as opposed to 1,848 gm of $U^{235}$). The resonance escape probability, one of the crucial items of information, turned out higher than expected—0.96–0.98 instead of the predicted 0.89–0.93.

The full-power operation was without incident except for the discovery of a pinhole in the cladding of an element soon after startup. Although the level of the escaped gaseous fission products did not necessitate shutting down the reactor, the defective element was replaced as a precaution.

Although the 20% fuel has proved itself operationally, further improvements in fabrication are required to eliminate the currently high rejection rate, now a major cost factor.

* D. R. deBoisblanc, R. S. Marsden. Preliminary evaluation of the 20% enriched uranium core for the MTR, IDO-16459 (1958).



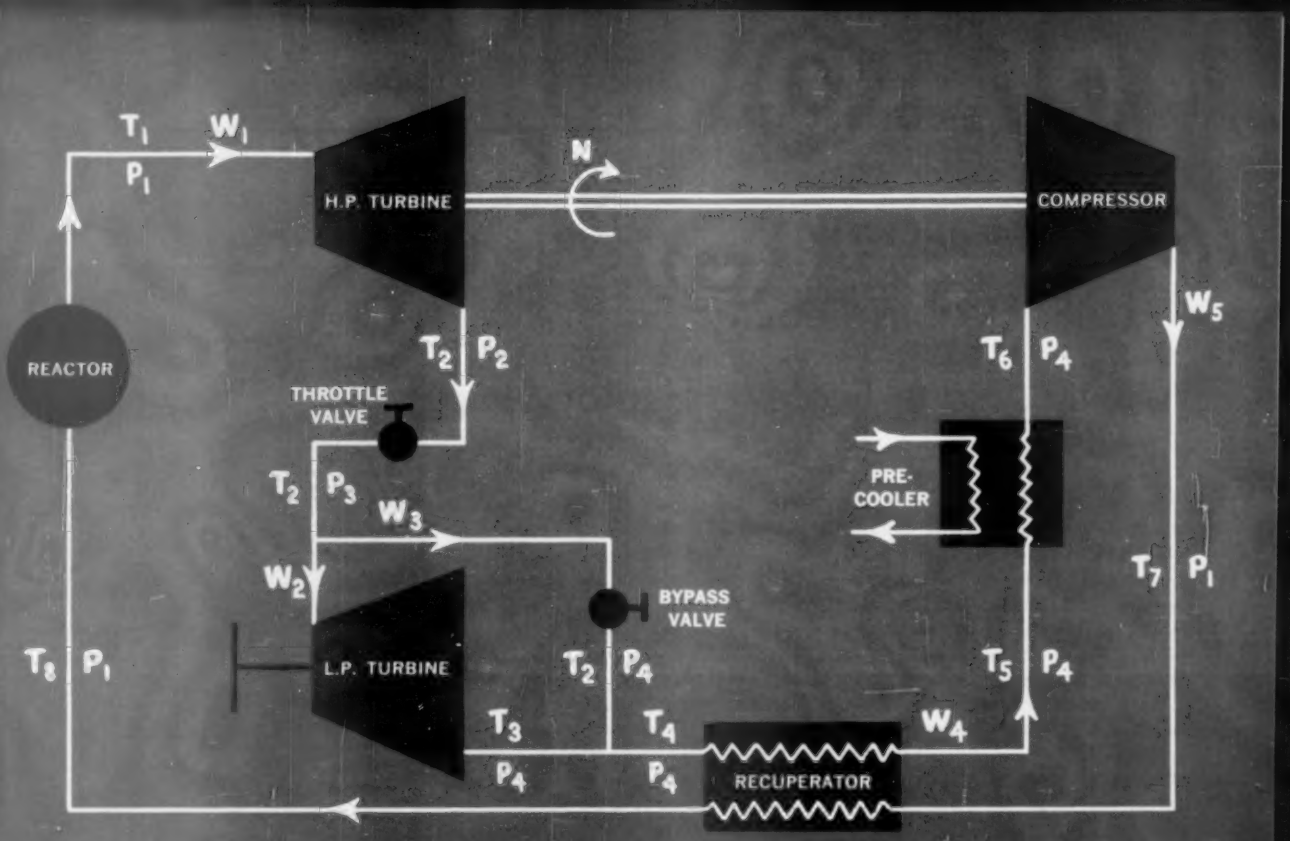
## High Temperature Materials Progress

Two developments just announced by Minnesota Mining & Manufacturing Co. may be applicable to high-temperature, gas-cooled reactors. The first is a silicon-carbide coating that renders graphite impervious to high-temperature, high-velocity gases. Coated-graphite samples exposed to air for several hundred hours at 1,000° C showed no weight change; other tests in He, air, $CO_2$ and steam at temperatures as high as 1,400° C were equally encouraging; no erosion was produced by 1,000° C-air flowing past the samples at 2,000 fps for 1,000 hr. The coating, which has been used in thicknesses of 0.5–10 mills, has shown good resistance to thermal shock.

Shown above (left) are components of a coated-graphite-canned fuel pellet; the $UO_2$ pellet is sealed in the can with a coated-graphite lid.

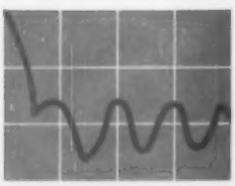
The second development is a technique for fabricating intricate shapes such as the corrugated ones shown above (right) from virtually any refractory material. The new technique (which does *not* use pressing or extrusion) has already been used to sandwich fuel between thin refractory sheets.

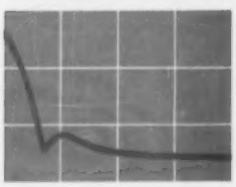
Both of these developments will be looked at with interest by designers of propulsion reactors (NU, Jul '58, 66), high-temperature test reactors (NU, Feb '58, 64) and gas-cooled power reactors (see p. 128).




# Digital analysis tests reactor system

## ...without spending a nickel on hardware





The problem was to evaluate performance of the complete reactor power system design, shown blocked out in preliminary form above.

It was natural for Ford Instrument nuclear engineers to turn to the digital computer for this. They have two of them on hand—one with accessories for differential analysis—as well as experienced programmers. Ford also has access to the vast computing facilities of Remington Rand Univac Division of Sperry Rand. The flexibility, high speed and accuracy of digital techniques were especially applicable to this type of engineering analysis.

Partial results of digital analysis are shown in the two available power vs. time curves at left. They show the effects of a change in throttle and bypass valve settings. Initial analysis revealed the poorly damped oscillatory curve at top left. After a simple system modification, reanalysis produced the smooth change and quick settling of the lower curve. *All without a nickel spent on hardware!*

Reactor system simulation is only one of the nucleonic activities at Ford Instrument Co. Others include: Design of a complete closed-cycle gas-cooled reactor; development of fuel elements, including high temperature studies; manufacture of control rod drive mechanisms (e.g., those used in the submarine *Seawolf*); control rod position indicators; magnetic and transistor amplifiers for nuclear applications; and studies of control rod and reactor materials. In addition, Ford Instrument is conducting numerous feasibility and experimental studies in the nuclear field, including the application of digital techniques to reactor control.

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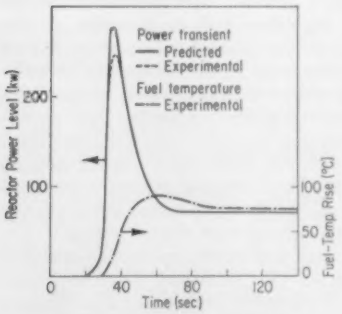
## GENEVA PREVIEW

# U. S. Exhibits Reactor with Unique Fuel-Moderator

TRIGA, a training, research and isotope-production reactor designed by General Atomic, has been selected by the AEC as one of two operating reactors to be included in its technical exhibit at the 1958 Geneva Conference. (The other reactor so chosen is Argonne's Argonaut.) This choice of TRIGA reflects its simplicity of construction and ease of operation. Installed in a 20-ft pit, the surrounding earth and 16 ft of water above the core (right) provide all the shielding that is required. But the most significant feature is the reactor's inherent safety.

TRIGA's safety stems from its unique core, which has a large and very prompt negative temperature coefficient. The core's aluminum-clad fuel elements contain a homogeneous blend of fuel and moderator in the form of uranium-zirconium hydride. This intimate mixture of moderator and fuel provides a prompt self-regulating mechanism because there is no time delay between fuel and moderator heating. The average energy of the thermal neutrons immediately increases, leading to a prompt decrease in reactivity resulting from a decrease in the effective fission cross section. In addition, the usual Doppler effect in $U^{238}$ is operative.




**Very prompt negative temperature coefficient of TRIGA is reflected in its transient behavior. After 75¢ reactivity insertion power rises but quickly levels off without large fuel-temperature rise. Energy release is 5 times less than for comparable reactivity insertion in other reactors**

These unique fuel elements are made by arc-melting uranium and zirconium and extruding the resultant billet. The extrusion is machined to size, hydrided in a hydrogen-atmosphere furnace and assembled with 4 in. of graphite at each end separated from the fuel-moderator by a thin samarium (burnable-poison) disk. An aluminum sheath is drawn over the assembly and end fittings are welded to the sheath ends to form a 26-in.-long element.

### Isotope-Production Facilities

Operating at 10 kw with an irradiation flux of $10^{11}$ n/cm²/sec, TRIGA will produce radioisotopes of 62 of the first 83 elements in specific activities ranging from 0.1 to several thousand mc/gm. As an example, 40 c of a radioisotope of 1-day half-life could be removed each day the reactor operated continuously.

The rotary specimen rack located in the water-tight, aluminum-lined well in the graphite reflector is the primary isotope-production facility. Other potential facilities include a rabbit tube for isotopes with short half-lives and a 1.5-in.-dia central thimble that occupies the position of maximum neutron flux. In addition, the top and sides of the reflector can be used to activate samples too large to fit into the other facilities.

The rotary specimen rack, "lazy susan," consists of an aluminum ring from which are suspended 40 aluminum cups. Specimen containers are loaded into the cups through a single pipe (this assures that only a minimum of gamma radiation will reach the surface). The lazy susan is rotated by a hand crank that is connected to it through another pipe.

### This is TRIGA . . .

### These are its Characteristics . . .

| | |
|---|---|
| Power—continuous: | 10 kw |
| —intermittent: | 30 kw |
| **Core tank** | |
| Height: | 19 ft 8 in. |
| Inside diameter: | 6 ft |
| Wall thickness: | ½ in. |
| Composition: | aluminum |
| **Core** | |
| Configuration: | right cylinder |
| Size: | 17 in. dia × 14 in. |
| Fuel load: | ~2.2 kg $U^{235}$ |
| Burnable poison: | samarium |
| Reflector | |
| —material: | graphite |
| —thickness: | 12 in. |
| **Control rods** | |
| Number: | 3 |
| Composition: | $B_4C$ |
| Total rod worth: | 3.0% $\Delta k/k$ |
| **Fuel elements** | |
| Number: | 60 |
| Enrichment: | 20% |
| Meat dimensions: | 1.42 in. dia × 14 in. |
| Meat composition | |
| —U: | 8 wt% |
| —ZrH: | ~92 wt% |
| Cladding: | aluminum |
| **Moderator** | |
| Type: | zirconium hydride |
| Thermal-neutron flux—avg: | ~$1.5 \times 10^{11}$ nv |
| —max: | ~$2.5 \times 10^{11}$ nv |
| Prompt-neutron lifetime: | $1.5 \times 10^{-4}$ sec |
| Prompt temp. coefficient: | ~$-6 \times 10^{-5}$/°C |
| Void coefficient: | $-1 \times 10^{-3}$/% void |
| Endurance: | 87,600 FPH |
| **Coolant** | |
| Type: | light water |
| Flow: | 13 gpm |
| Temp.—inlet: | 50° F |
| —outlet: | 55° F |
| Core channel velocity: | 0.05 fps |

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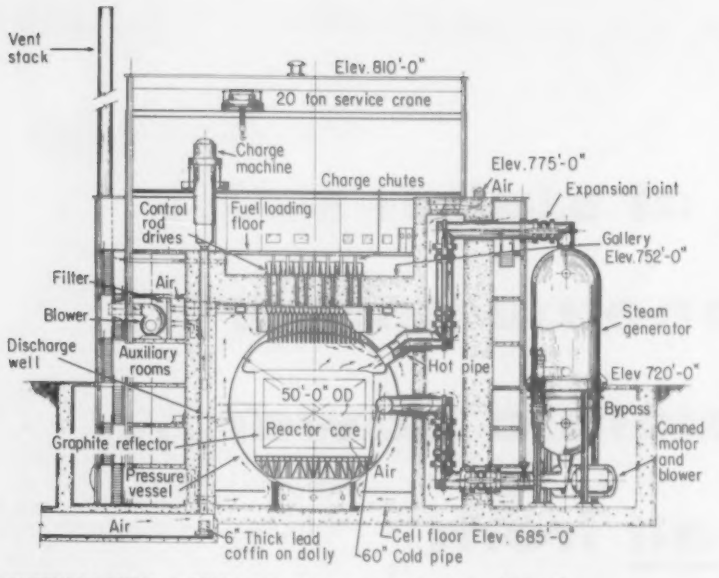


**SECTIONAL VIEW of ORNL's full-scale gas cooled reactor (GCR-2)**

# U. S. Designs Gas-Cooled Reactors

The gas-cooled reactor concept has just emerged from a thorough going-over by the AEC to determine whether the U. S. should support a development program in this area. After seven months of concentrated effort by ORNL, Kaiser Engineering, ACF Industries and Hanford, the AEC has presented its conclusions and results in the form of three comprehensive reports (see box). These reports represent an up-to-date evaluation of both the present U. S. capability for building gas-cooled plants and the future economic potential of this plant type in the U. S.

As a result of its studies the AEC feels that the U. S. has enough technical knowledge to start building gas-cooled reactors as advanced as any now being built in the world. In fact the natural-uranium full-scale design developed by KE-ACF (see table) proposes significant improvements over the most advanced of the British designs. In a recent talk on the U. S. gas-cooled reactor program* Clark Goodman characterized the KE-ACF natural-U design as a jump by U. S. designers from Calder Hall to beyond Hinkley Point. He pointed out that in terms of specific parameters the biggest jumps have occurred in the coolant-gas pressure and outlet temperature. This is also true of the full-scale enriched designs proposed by ORNL and KE-ACF.

Since the thermal performance of a gas-cooled reactor is quite sensitive to these two parameters, any conclusion drawn about the economics of the U. S.

* Meeting of the Washington, D. C. Chapter of American Nuclear Society, May 1, 1958.

**Summary of U. S. and Foreign Gas-Cooled Reactor Characteristics**

| | Kaiser-ACF | | | | ORNL | United Kingdom | | | France |
|---|---|---|---|---|---|---|---|---|---|
| | *Natural U* | | *Partially enriched U* | | *Part. enr. U,* | *Natural U* | | | *Nat. U,* |
| | *Prototype* | *Optimum* | *Prototype†* | *Optimum* | *Optimum* | *Calder Hall* | *Bardwell* | *Hinkley Pt.* | *Chinon* |
| Heat output [Mw(th)] | 180 | 700 | 125 | 600 | 700 | 182 | 530 | 980 | 300 |
| Net electrical output [Mw(e)] | 55 | 220 | 44 | 215 | 225 | 35 | 150 | 250 | 60 |
| Net thermal efficiency (%) | 30.6 | 31.4 | 35.3 | 35.8 | 32.1 | 19.0 | 28.3 | 25.5 | 20 |
| Specific power [Mw(th)/metric ton] | 1.85 | 2.55 | 6.9 | 7.9 | 5.1 | 1.4 | 2.21 | 2.65 | 2.15 |
| Enrichment (%) | 0.71 | 0.71 | 3.0 | 2.5 | 2.0 | 0.71 | 0.71 | 0.71 | 0.71 |
| Uranium loading [metric tons] | 97.5 | 274 | 18.0 | 77 | 137 | 130 | 240 | 370 | 140 |
| $U^{235}$ inventory (kg) | 692 | 1,960 | 540 | 1,925 | 2,740 | 925 | 1,700 | 2,630 | 1,000 |
| Fuel material | U metal | U metal | $UO_2$ | $UO_2$ | $UO_2$ | U metal | U metal | U metal | U metal |
| Cladding material | Magnox A12 | Magnox A12 | SS304 | SS304 | SS304 | Magnox C | Magnox A12 | Magnox A12 | Mg alloy |
| Average fuel exposure (Mwd/metric ton) | 3,000* | 3,000* | 10,000 | 10,000 | 7,350 | 3,000 | 3,000 | 3,000 | — |
| Refueling | Operation | Operation | Operation | Operation | Shutdown | Shutdown | Operation | Operation | Shutdown |
| Core diam × ht (ft) | 35 × 25 | 50 × 29 | 12.2 × 18.5 | 20 × 26 | 20 × 30 | 31 × 21 | 40 × 26 | 49 × 25 | 28 × 30 |
| No. of fuel channels | 1,532 | 3,536 | 344 | 980 | 1,597 | 1,696 | 2,620 | 4,500 | 1,140 |
| Coolant | $CO_2$ | $CO_2$ | $CO_2$ | $CO_2$ | He | $CO_2$ | $CO_2$ | $CO_2$ | $CO_2$ |
| Coolant pressure (psia) | 285 | 285 | 400 | 400 | 300 | 100 | 165 | 175 | 356 |
| Coolant outlet temp. (°F) | 800 | 800 | 1,000 | 1,000 | 1,000 | 637 | 734 | 707 | 673 |
| Coolant inlet temp. (°F) | 409 | 413 | 463 | 473 | 450 | 285 | 356 | — | 284 |
| No. of coolant loops | 2 | 8 | 2 | 6 | 4 | 2 | 6 | — | 1 |
| Press. vessel I.D. × ht (ft) | 36 × 66 | 70 | 18 × 40 | 27 × 57 | 50 | 37 × 70 | 67 | 80 | 33 × 44 |
| Press. vessel wall (in.) | 4 | 4 | 3 | 4 | 3.25 | 2 | 3 | 3 | 4.2 (cyl. wall) |
| H.P. steam press. (psia) | 1,450 | 1,450 | 2,400 | 2,400 | 950 | 210 | 765 | 650 | 307 |
| H.P. steam temp. (°F) | 750 | 750 | 950 | 950 | 950 | 590 | 704 | 685 | 650 |
| L.P. steam press. (psia) | 300 | 300 | 750 | 750 | (single pressure cycle) | 63 | 209 | 195 | 61 |
| L.P. steam temp. (°F) | 750 | 750 | 950 | 950 | | 340 | 704 | 670 | 433 |

* Assumes fuel rotation limiting high temperature exposure to 1,500 Mwd/ton. Alternate 2-region core also proposed; nat. U in $UO_2$ with stainless steel cladding for inner region and U metal with Magnox A12 cladding for outer region to permit 3,000 Mwd/ton at 800° F.

† See p. 120 for subsequent design changes.

## Recent U. S. Gas-Cooled Reactor Studies

### ORNL Gas-Cooled Reactor (GCR-2)*

This is a detailed design study of a 225-Mw(e) enriched gas-cooled reactor (see figure) prepared by the Oak Ridge National Laboratory staff for the AEC between September 1957 and March 1958. The four-volume report proposes a reactor design that is based on existing technology and on which construction could begin today if desired. The important parameters are compared with those of other gas-cooled reactors in the table on the opposite page. The principal differences from the British designs are the use of stainless-steel fuel-element clad, enriched-$UO_2$ fuel and He gas coolant. ORNL estimates that the plant could be built for $420/kw; at 80% plant factor and 7,400 Mwd/ton the total power cost would come to 12.1 mills/kwh.

Besides the design study ORNL has been and will continue to be involved in a broad experimental program devoted to gas-cooled problems. The topics under investigation (and reported on in ORNL 2505) include:

- Fabrication and in-pile test of $UO_2$ fuel elements
- $CO_2$-C reaction studies
- Heat transfer and pressure drop studies
- Pressure-vessel welding and inspection methods
- Pressure-vessel radiation effects

### Kaiser-ACF Survey†

In parallel with the ORNL work the AEC selected Kaiser Engineers (with ACF Industries, Inc., as subcontractor on nuclear and reactor design) to carry out four gas-cooled design studies. These included:

- Feasibility study of a full-scale [200 Mw(e)] natural-U plant optimized for minimum power cost.
- Preliminary (Title I) design of a 55-Mw(e) prototype for plant mentioned above, including an evaluation with partially enriched as well as natural fuel.
- Feasibility study of a full-scale [215 Mw(e)] partially enriched plant optimized for minimum power cost.
- Feasibility study of a 44-Mw(e) prototype for this last plant.

The design parameters for these plants are summarized in the table. Power-cost estimates for the natural-U and enriched-U full-scale plants led KE-ACF to the conclusion that in the U. S. enriched and naturally fueled gas-cooled plants would have the same fuel costs (assuming 3,000 Mwd/ton for natural U and 10,000 Mwd/ton for enriched U) but that the capital investment would be significantly higher for natural U ($640/kw as compared with $490/kw). For an 80% plant factor the total power costs for the natural U design were estimated at 16.2 mills/kwh and for the enriched design 13.4 mills/kwh.

Following the above tasks KE-ACF has been working on the Title I design of the enriched prototype (see box, p. 120) which it hopes to finish in October.

### Hanford Parametric Study‡

This is the third of the three gas-cooled studies authorized by the AEC last fall. It summarizes the results of a parametric study of advanced gas-cooled power reactors with exit gas temperatures from 1,000° to 1,400° F and for both indirect steam-cycle and direct gas-turbine-cycle schemes. In general the study gives technical support to the KE-ACF and ORNL work.

### General Nuclear Engineering Corp. Reactor§

General Nuclear has given considerable effort to the design of a high temperature, $D_2O$-moderated, gas-cooled reactor. The coolant gas, either $CO_2$ or He, would be at 500 psi and would have a core-outlet temperature of 1,050° F. The fuel would be $UO_2$ clad either with Be, "alloy steel" or possibly a ceramic. A proposed 180-Mw(th) prototype would have a fuel enrichment of 1.15% the full scale version [~200 Mw(e)] is expected to operate on natural or near-natural U. The relatively high coolant-gas pressure is made possible by using a pressure-tube design (the gas is contained by tubes that surround the individual fuel elements and are welded to headers at each end; the space between the tubes is filled with the $D_2O$ at a lower pressure.)

General Nuclear predicts a fuel lifetime of 4,000 Mwd/ton for the $D_2O$-natural U combination. Estimates based on this figure arrive at a fuel cost of 0.035 mills/kwh assuming Pu credit at $12/gm and 1.2 mills/kwh assuming no Pu credit. The high-pressure high-temperature design allows a specific power of 10 Mw/ton of fuel; this compares with 15 Mw/ton for PWR and only 2.6 Mw/ton for Hinkley Point.

---

* ORNL 2500 (April 1958); ORNL 2505; ORNL 2510.

† NU, May '58, 104; KE-ACF Report Nos. 58-1-RE, 58-2-RE, 58-3-Re, 58-4-RE.

‡ HW 54727, HAPO, General Electric Co.

§ Sponsored by the East Central Nuclear Group and the Florida West Coast Nuclear Group; description taken from testimony by W. H. Zinn before the JCAE March 3, 1958.

designs hinges on the feasibility of these suggested design improvements.

**Pressure-vessel thickness.** The system pressure in a gas-cooled reactor is limited directly by how thick a pressure vessel can be fabricated. But, because of its size, the reactor pressure vessel must be welded and stress-relieved on site. This involves assembling and welding the parts of a large (~70 ft) sphere, annealing the whole structure by heating it to 600° C and making radiographic inspection of the welds. The practical difficulties of these operations increase with vessel thickness and set the final limit on this engineering parameter.

The British, with the experience of the 2-in. Calder Hall vessel under their belt, feel they must limit themselves to 3 in. on their new Hinkley-Point-type designs.* On the other hand the U. S. designers to achieve the higher design pressures have specified 3.25-in. and 4-in. thicknesses for the ORNL and KE-ACF pressure vessel designs respectively.

According to ACF, justification for the 4-in. thickness was found in a survey of American industrial capabilities. Although no vessels of this thickness have yet been built in the U. S. with diameters as large as 70 ft, eleven American firms foresaw no insurmount-

* The French have reported recent success in welding a 3-in. vessel.

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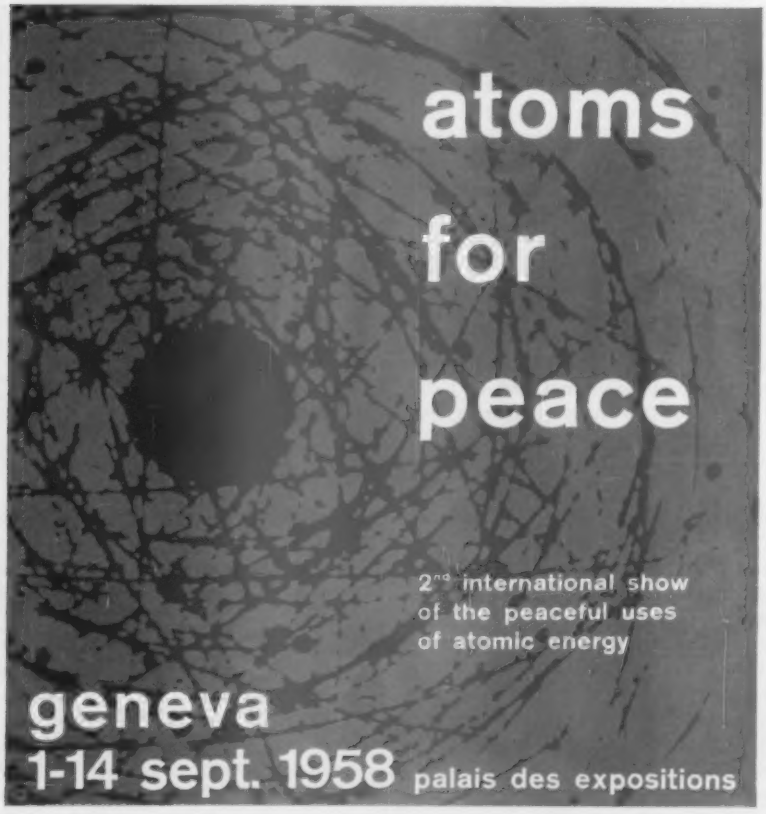




*This article starts on page 118*

## Enriched Prototype Changes

**Since KE-ACF's enriched-prototype proposal was singled out in March as the first logical step for a U. S. gas-cooled-reactor program, further deliberations have reduced the power to 35 Mw(e) and have changed the coolant from $CO_2$ to He. Work by KE-ACF on the Title I design showed that the minimum power for a useful prototype was lower than had been thought; hence the 35 Mw.**

**The reasons for going to He cooling included:**

- **Concern about the $CO_2$-C reaction uncertainty.**
- **Reduced concern about engineering a leakproof He circuit.**
- **The feeling that a He system would be more of a contribution to world knowledge (especially since the U. K. plans to build advanced $CO_2$ systems).**
- **With no $CO_2$-C reaction to limit temperatures, fuel elements can be pushed to their thermal capacity.**

**At present the designers are planning an initial outlet temperature of 1,050° F plus the capability to go as high as 1,200° F as soon as the fuel elements permit.**

able problems for vessels of this thickness and size; four companies (M. W. Kellogg, Chicago Bridge & Iron, Consolidated Western and Kaiser Steel) were willing to quote fixed prices on complete erection, fabrication and stress relief for any of the four vessels proposed by KE-ACF.

**Outlet temperature.** The elevated gas outlet temperatures quoted for the U. S. designs also require explanation. To heat the coolant gas to the temperatures shown the fuel elements must operate at temperatures beyond the range of either U. S. or British experience. In the KE-ACF natural-U design, for example, the 800° F outlet temperature means that maximum hot-spot surface temperature for the Magnox clad will be over 900° F.

The main detrimental effect of the higher temperatures in the U. S. reactors is expected to be an increase in fuel-element swelling under fission-product-gas pressure. In the natural-U proposal this is compensated for by a scheme to rotate the fuel so that no element would receive more than half of its total 3,000 Mwd/ton exposure while in the high temperature

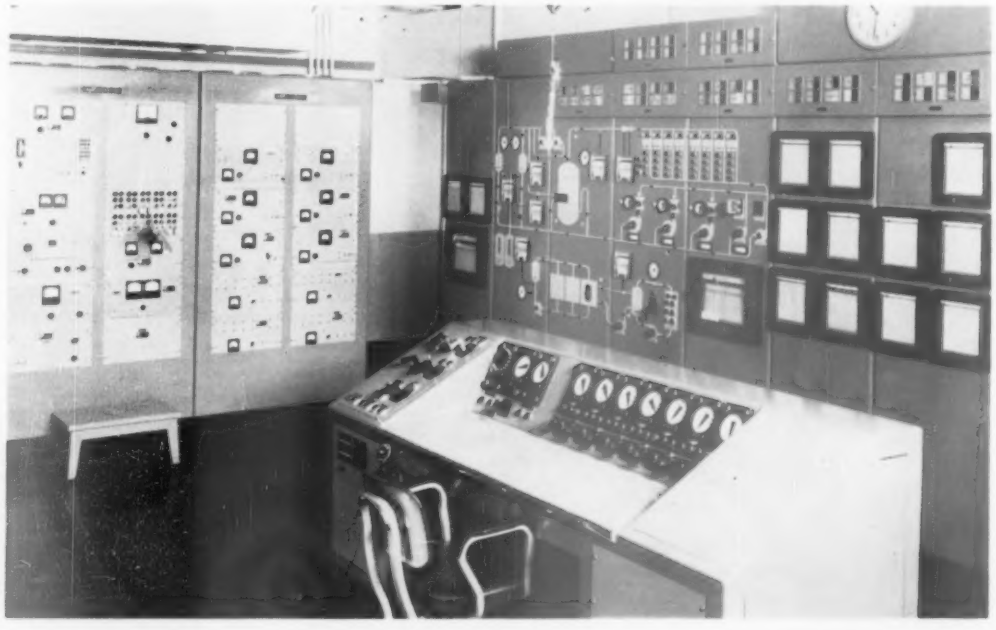
# ORR on the Line

ORR went critical on March 21, 1958 with 1,366 gm of fuel in the reactor. From observation of the excess reactivity available, critical mass was estimated to be 1,280 gm. Calculations had predicted a critical mass of 1,150 gm, but these were based on a thicker reflector than was actually used.

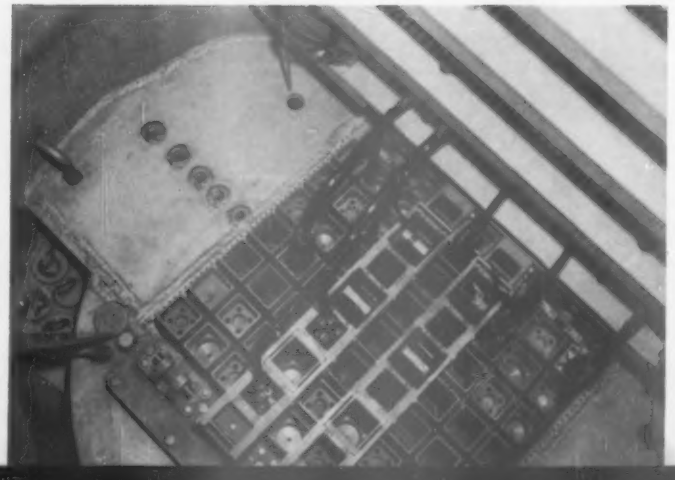
In the initial loading, the active region of the core was a three-by-three grid with five elements, each containing 168 gm of $U^{235}$, and four control rods, each containing about 131 gm of $U^{235}$. The remainder of the core was filled with beryllium reflector elements and water.

In a subsequent loading, the core was expanded to a four-by-seven array containing 3,324 gm of $U^{235}$. Calibration by means of distributed poison showed that the amount of excess $k$ was ~14% and that the total worth of the four control rods was about 30% $\Delta k/k$. This was in good agreement with previous estimates.

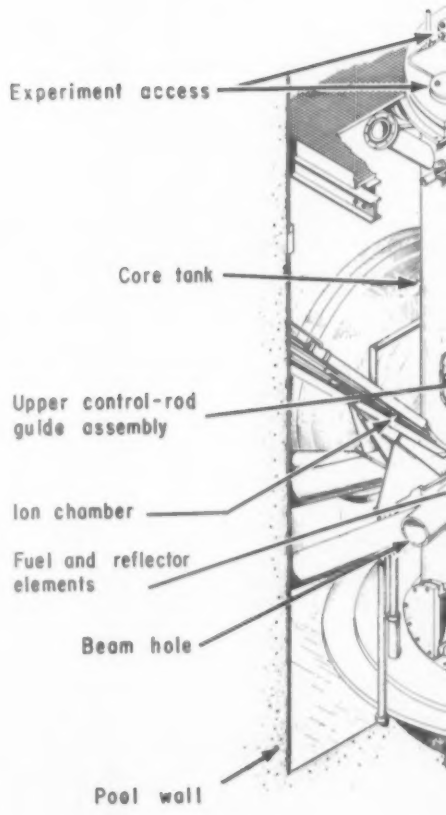
ORR was first operated at 20 Mw(th) on May 29, 1958. It will normally be operated 24 hr a day as a source of neutrons and gamma rays for basic research, engineering test and radioisotope production.



**1** ORR control room. Wall panels show process instrumentation for two separate coolant systems; top loop is for reactor, bottom loop for pool



**2** ORR core set up for hydraulic flow measurements shows one of many possible arrangements; 4 control rods are surrounded by 26 fuel, 33 reflector elements




**3** Reactor sits on bottom of one end of pool with
drives in subpile room in basement of reacto
Reactor coolant enters above core, flows do

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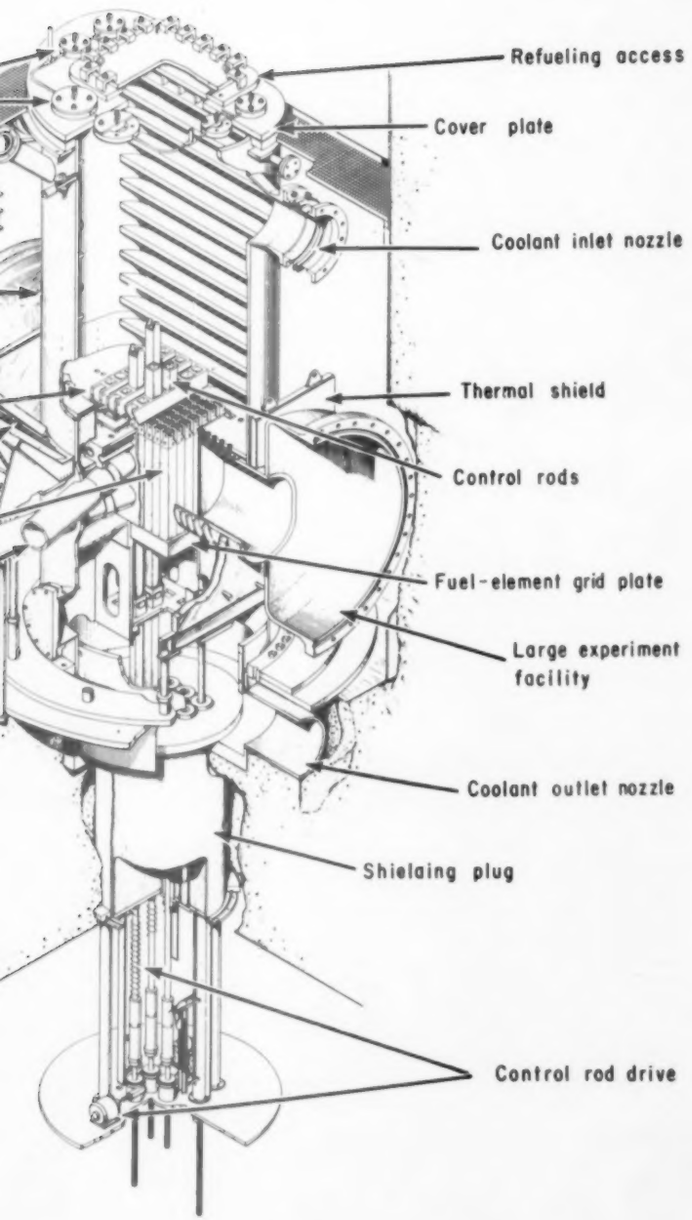
This foldout is removable tear along perforation




ol with control-rod
f reactor building.
ows down through

fuel elements, control rods, etc., and exits just above bottom shield plug. Core tank cover plate has refueling and experiment access ports

yright on the August 1958 issue—NUCLEONICS, 330 W. 42nd St., New York, N. Y.

# Characteristics of ORR

| | |
|---|---|
| Location: | Oak Ridge, Tennessee |
| Designer: | Oak Ridge National Laboratory |
| Operator: | Union Carbide Nuclear Co. |
| Owner: | U. S. Atomic Energy Commission |
| Cost—design: | $556,000 |
| —construction: | $3,148,000 |
| —equipment: | $697,000 |
| —installation: | $265,000 |
| —total: | $4,666,000 |
| Initially at full power: | May 29, 1958 |
| Full-power level: | 20 Mw(th) |

## Component Design Data

### Core tank

| | |
|---|---|
| Height: | 14.8 ft |
| Inside diameter: | 5.3 ft (nominal) |
| Wall thickness: | 1.75 in. |
| Composition: | aluminum (A528, A548) |
| Design pressure: | 28 psig |
| Test pressure: | 38–60 psig |

### Core

| | |
|---|---|
| Configuration: | right parallelepiped |
| Size: | 27 × 22 × 24 in. (max.) |
| Fuel load: | variable (3–4 kg $U^{235}$) |
| Composition | |
| —water: | 60.4 vol% |
| —aluminum: | 39.4 vol% |
| —uranium: | 0.2 vol% |

### Control rods

| | |
|---|---|
| Configuration: | modified square tube |
| Number: | 12 (max.) |
| Absorber | |
| —material: | cadmium |
| —length: | 30.5 in. |
| Follower | |
| —material: | Al-U |
| —length: | 23.6 in. |
| Weight: | 32 lb |
| Total rod worth: | 30% $\Delta k/k$ |
| Withdrawal rate: | 5 in./min |

### Control-rod drives

| | |
|---|---|
| Type: | lead screw and nut |
| Number: | 12 (max.) |
| Power requirement: | 120 v, 1 $\phi$ |
| Motor rating: | 1,800 rpm, $\frac{1}{8}$ hp |
| Position-indicator accuracy: | ±0.01 in. |

### Fuel elements

| | |
|---|---|
| Type: | plate |
| Number: | 51 (max.) |
| Enrichment: | 90% |
| Plates per element: | 19 |
| Plate dimensions: | 24.625 × 2.8 × 0.05 in. |
| Meat composition | |
| —uranium: | 14–18.5 wt% |
| —aluminum: | 86–81.5 wt% |
| Cladding: | 28 Al |
| Plate temp. | |
| —avg: | 160° F |
| —max: | 210° F |

## Nuclear Design Data

### Moderator

| | |
|---|---|
| Type: | light water |
| Average neutron energy: | ~0.03 ev |
| Thermal-neutron flux—avg: | $1.4 \times 10^{14}$ n/cm²/sec |
| —max: | $3.4 \times 10^{14}$ n/cm²/sec |
| Prompt-neutron lifetime: | $\sim 10^{-4}$ sec |
| Over-all temp. coefficient: | $-6.8 \times 10^{-5}$/° F |

### Control requirement

| | |
|---|---|
| Burnup: | 3.3% $\Delta k/k$ |
| Xenon: | 3.9% $\Delta k/k$ |
| Samarium: | 1.0% $\Delta k/k$ |
| Temperature: | 0.4% $\Delta k/k$ |
| Experiments: | 5.0% $\Delta k/k$ |
| Operating margin: | 1.0% $\Delta k/k$ |
| Total: | 14.6% $\Delta k/k$ |

## Heat Transfer Data

### Coolant

| | |
|---|---|
| Type: | light water |
| Volume | |
| —reactor loop: | 59,000 gal |
| —pool: | 120,000 gal |
| Flow: | 12,000 gpm |
| Temperature | |
| —inlet: | 120° F |
| —outlet: | 131.4° F |
| Pressure: | atmospheric |
| Core channel velocity: | 20 fps |

### Heat flux

| | |
|---|---|
| Max/avg ratio | |
| —axial: | 1.7 |
| —radial: | 1.4 |
| Core—avg: | 140,000 Btu/ft²/hr |
| —max: | 400,000 Btu/ft²/hr |

NUCLEONICS REACTOR FILE . . . NO. 6

Reactors on the Line

ORR

Oak Ridge Research Reactor

# Description of ORR

The Oak Ridge Research Reactor (ORR) was designed to serve as a general-purpose research tool. The design is an attempt to combine the high flux of a tank-type reactor, such as the Materials Testing Reactor (MTR), with some of the ease-of-access characteristics of a swimming-pool type. ORR is essentially a swimming-pool reactor in which, instead of being exposed to pool water the core is enclosed in a tank and has a separate forced-circulation cooling system.

Several other features of the ORR distinguish it from other research reactors. One, the location of control-rod drives below the core, leaves the area above the core free for insertion of experiments. Another, a hot cell located above the far end of the pool, provides ease in handling, inspecting and dismantling small experiments, freshly produced isotope samples, etc.

## Core Tank

The reactor vessel is an aluminum tank that is flat on one side. The base of the tank is mounted on the bottom of the beam-port end of the pool, with the flat side facing the opposite end. The tank is an all-welded structure of three sections. The bottom section is heavily ribbed and provides support for the lower control-rod bearings, the fuel-element grid plate and baffles that direct the flow of coolant to the two outlet nozzles at the bottom of the tank, ~6 ft below the core, and from thence to the exit manifold.

The middle section provides support for the core housing. Six beam ports pierce the tank in this section and terminate at a face of the housing as do the two 25-by-19-in. obround sections of the large experimental facilities that are on either side of the core. With a pool depth of 28½ ft, the middle section is located such that the centerline of the core is 24 ft below the pool-water level.

The top section serves to straighten out the flow of coolant entering through two nozzles ~8 ft above the core. The height to the top flange of the tank was determined by the requirement that the pool water could be lowered to the cover plate for the insertion of experiments and still maintain sufficient water shielding above the core (10 ft from center of core to tank flange).

The flat side of the tank was incorporated in the design to provide access to the pool side of the core for experiments. The entire height of the flat side is reinforced on the inside with 2-by-4.5-in. ribs.

The main cover plate is semipermanently installed and would be removed only for major maintenance work on the core. A smaller, rectangular cover plate is clamped in place and can be remotely removed and replaced for refueling operations without lowering the pool water. Six circular cover plates are provided for access into the core tank for in-pile experiments.

## Core Structure

The reactor core structure consists essentially of the fuel-element grid plate, core housing and upper control-rod guide assembly. The fuel elements have square end-adapters and are supported on the stainless-steel grid plate in such a manner that the elements will stand upright during loading. Each element, and the inside of the core housing, is fitted with accurately machined buttons that provide a maximum of 0.002 in. of clearance between elements. Because of the design of the grid plate and end adapters, and because the coolant flows downward through the core, no upper grid plate is required such as would hamper the insertion of in-pile experiments.

The core housing is a rectangular structure 29-by-24 in. in cross section and 30 in. high. Because of the high gamma heating in the sides of the housing, it was necessary to perforate them with 0.188-in. holes to prevent boiling.

The control rods are guided through the core by means of stainless-steel roller bearings, one set of which are located 18 in. below the grid plate in the bottom section of the core tank. A second set is located in each of from one to four control-rod guide assemblies that are hinged to the top of the core housing.

## Control Rods

The ORR control rod is a welded aluminum assembly 9.75 ft long. The active portion of the rod consists of an absorber section and a follower section. The absorber section is made up of a 32.5-by-9.25-by-0.040-in. piece of cadmium canned in an aluminum jacket, formed into a square tube and fitted into an aluminum extrusion of the same outside shape as the fuel elements.

The follower section is 27.125 in. long and contains 14 fuel plates of the same composition and shape as those in the fuel elements. Below the follower section is additional aluminum extrusion to add the length to the rod that is required to enter the shock absorber. Attached to the lower end of this extension is a stainless-steel piston that forms part of the shock absorber.

## Control-Rod Drives

Each control rod is positioned by a separate drive mechanism that is located in the sub-pile room. Drive tubes extend up through the shielding plug to the space immediately below the core. A ball-latch mechanism located at the upper end of the drive tube engages a shoulder on the lower part of the control rod. The latch is kept engaged by an electromagnet. The drive tube is raised and lowered through the action of a lead-screw-and-nut that is, in turn, driven by a reversible induction motor. Scram is produced by de-energizing the magnet, and the rod falls while the drive tube remains stationary.

## Fuel Elements

The reactor uses MTR-type fuel elements. As is generally the case with this type element, the aluminum-uranium-alloy, aluminum-clad plates are curved. In fabrication, the fuel alloy is sandwiched between two aluminum plates and the combination rolled out to provide a core of fissionable material completely covered by a strong, metallurgically-bonded cladding. The plates are brazed to aluminum sideplates that form a tube about 3 in. square. Spacing between the plates of 0.116 in. provides channels for the coolant.

Fuel elements that vary in their $U^{235}$ content some having as little as 70 gm and others 168 gm or more, have been provided. In addition, as few as five or as many as 51 elements can be placed in the reactor grid. Thus, the fuel loading can be changed to accommodate in-pile experiments. Typically, 24 elements are spaced in the seven-by-nine grid around four control rods to form the fuel region of the reactor. This region is surrounded by 35 elements of beryllium, which are similar in shape and dimensions, to form a relatively thin reflector that is backed up by ~4 ft of water.

## Experimental Facilities

Because of the flexibility of the reactor, a variety of experiments can be performed at the same time. Two large water-tight locks, each 5.5 ft in diameter, pierce the pool wall on either side of the reactor. In addition, six horizontal beam tubes, each 6 in. in nominal diameter, are available.

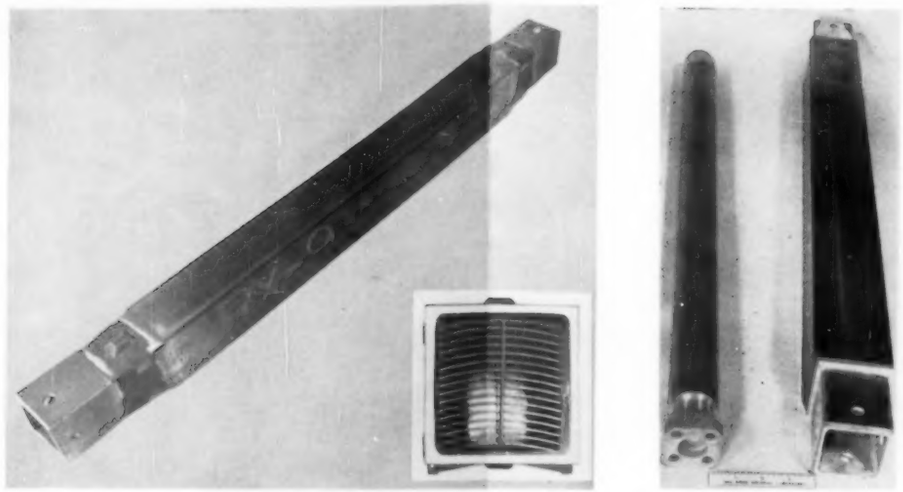
Insertion of experiments is possible in any of the 63 spaces in the reactor core grid, depending on lattice arrangements. Also, small experiments requiring outside connections can be placed in tubes and guided into the core through sleeves located in the core tank's top plate, and larger experiments, such as small fuel loops, can be inserted so that they can remain in the reactor even during refueling. The top plate of the core tank also has sufficient access openings for several "rabbit" tubes.

Some of the experiments that are to be conducted in the ORR include the following:

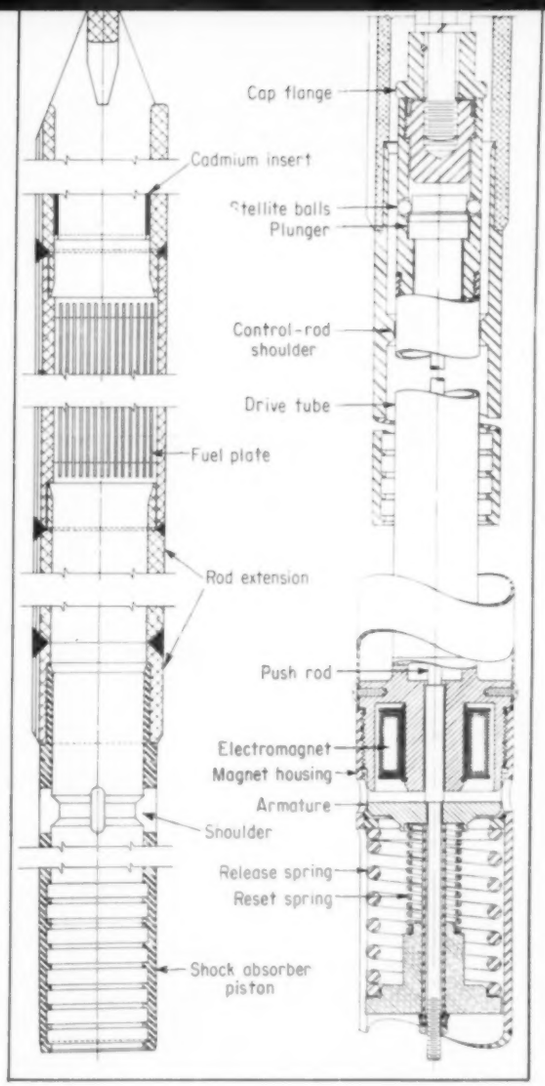
- Dynamic loop tests to determine the effects of radiation on fluid-fuel materials and equipment;
- Irradiation of fluid fuels in quantities large enough to make chemical studies of continuous fuel-processing systems;
- Investigations of radiation effects on engineering materials as well as basic studies of the properties of metals, alloys and ceramics (refractories);
- Neutron spectroscopy, neutron-time-of-flight and cross-section studies using external beams;
- Production of radioisotopes of greatly increased specific activity than was heretofore available.

* * *

*For more detailed information see* T. E. Cole, J. P. Gill, The Oak Ridge National Laboratory research reactor (ORR), a general description, ORNL-2240 (1957).

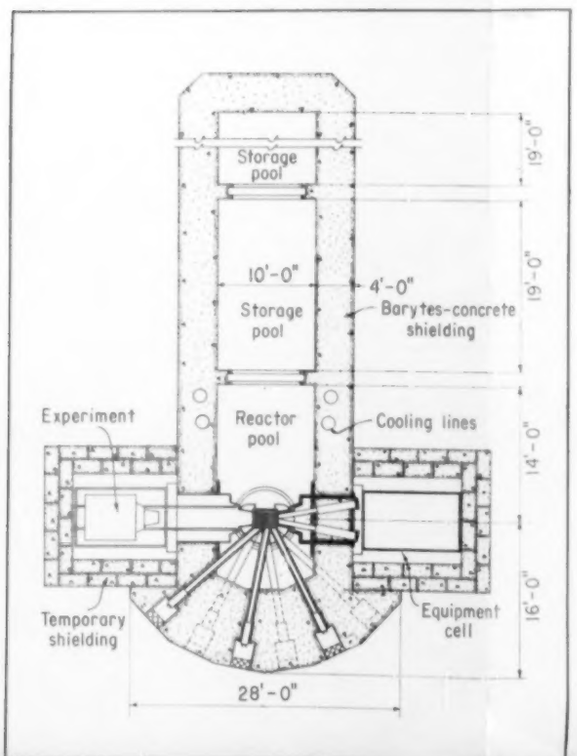


**4** ORR's MTR-type fuel element has curved plates of aluminum-uranium alloy clad with aluminum. Nineteen such plates are brazed to aluminum side plates, one of which has concave surface. Reflector element shown at right has removable beryllium center

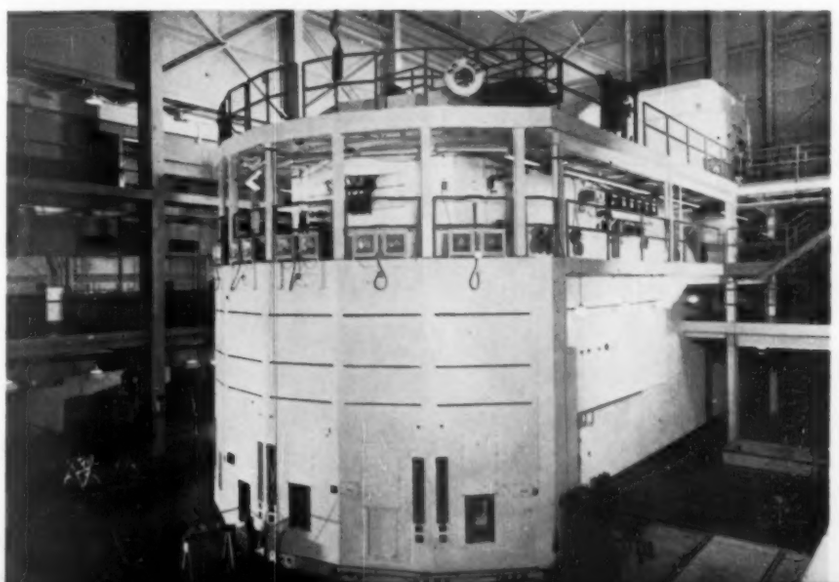



**5** Control rod (left) and control-rod drive in "down" position (right); in "up" position, control-rod shoulder would rest on balls. Control rod has 14-in. shock absorber, 37-in. extention, 27-in. fuel, 32-in. absorber and 7-in. top sections for over-all length of 117 in.

**6** Sectioned view through reactor pool structure shows two large experiment facilities on either side of reactor and six beam ports. Pool has three about equal sections closed off by gates




**7** Over-all view of ORR shows beam-hole end of pool wall. Balcony around pool is 5½ ft above second floor of reactor building and walkway atop pool wall is even with third floor. Hot cell can be seen above pool at far end



region of the core. In the enriched designs the ss-$UO_2$ fuel elements are counted on to resist swelling at surface temperatures of 1,300° F for exposures up to 10,000 Mwd/ton.

Clearly these proposed operating conditions must be thoroughly checked out by in-pile tests before the large-scale reactor designs can be frozen.

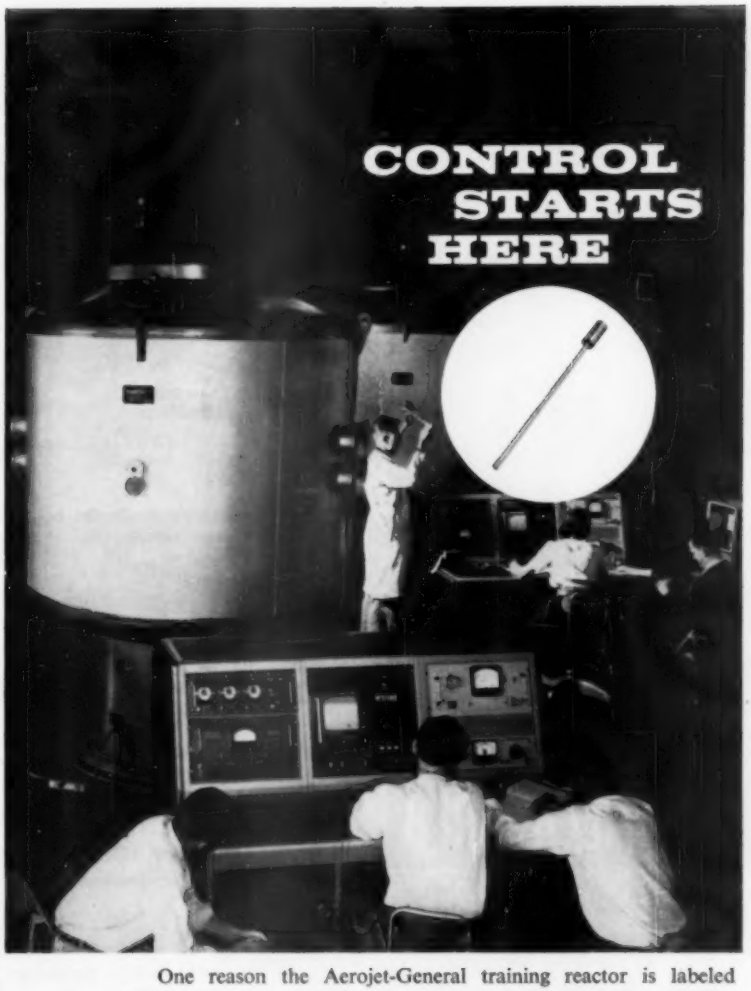
In its report to Congress the AEC fully recognized this need as follows: ". . . concurrent with any construction project, it would be necessary to undertake extensive research and development on fuel elements whether of metallic U with Magnox cladding for the natural version or nonmetallic U with stainless-steel or beryllium cladding for the partially enriched version."

Since the KE-ACF enriched design uses $CO_2$ as a coolant, it faces an additional uncertainty because of the high temperature $CO_2$-C reaction. As the outlet temperature is increased, at some point the mass transfer from the reaction will begin to foul heat transfer surfaces and weaken the graphite structure. British experience indicates with fair certainty that this limit is at least as high as 800° F; whether it is as high as 1,000° F is not yet known. In case the $CO_2$-C reaction does turn out to be troublesome in this region, the removable graphite coolant-hole sleeves called for in the KE-ACF design could be coated with an impervious material (for a recent development in this area see p. 114).

By using He coolant the ORNL design avoids the $CO_2$-C problem at the expense of developing leak-tight He blowers and valves and accepting the disadvantages of scarce He supply.

## Economic Conclusions

The AEC studies supported two conclusions about the economic facts-of-life for gas-cooled power reactors. First the KE-ACF work indicated (see box p. 119) that slightly-enriched designs would produce cheaper power in the U. S. than would natural-U designs. Second, both KE-ACF and ORNL found that the power costs estimated for their slightly enriched-reactor proposals are on a par with the estimates for advanced designs of other reactor concepts now being developed by the AEC: moreover the enriched gas-cooled system seems to offer as much development potential as, say, the pressurized-water reactor. Thus there seems to be no good reason why the AEC should not support development of the gas-cooled concept in parallel with its other activities.


One reason the Aerojet-General training reactor is labeled "world's safest" is its monitoring and control system which prevents premature criticality. Key component in this system is the radium-beryllium source developed and manufactured for AGN by United States Radium Corporation.

United States Radium Corporation has produced thousands of radiation sources for use in nuclear programs as well as in other areas of industrial technology and research. The company's neutron sources are encapsulated in stainless steel or Monel, designed for magnetic or mechanical handling. Special design configurations or encapsulating materials are available for radium-beryllium, radium D-beryllium, polonium-beryllium and actinium-beryllium. Neutron sources are supplied either calibrated or uncalibrated.

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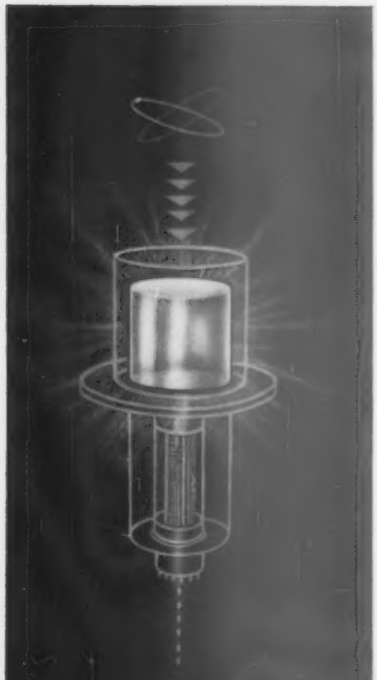

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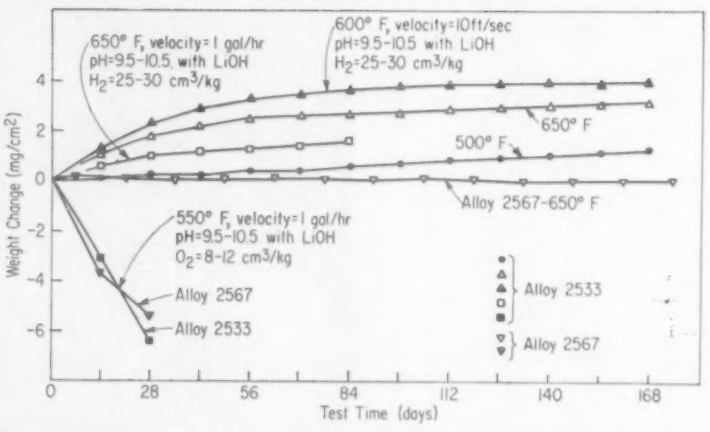


**FIG. 1. Corrosion-test results for Ag-In-Cd alloys in high-temperature water. Alloy 2533 is preirradiation composition (Ag-13.6 In-4.9 wt% Cd); 2567 is postirradiation composition (Ag-12.1 wt% In-9.4 wt% Cd-2.0 wt% Sn). If no water velocity is given, test was in static water**

# Ag-In-Cd Could Replace Hf for PWR Control Rods


By I. COHEN, E. F. LOSCO and J. D. EICHENBERG
*Bettis Plant, Westinghouse Electric Corp., Pittsburgh, Pennsylvania*


Test results would justify replacing hafnium with a silver-indium-cadmium alloy (Ag-15 wt% In-5 wt% Cd) in control rods of future pressurized-water-reactor cores.* Advantageous properties of the alloy are:

**Neutron capture**—Effectiveness of the alloy is 99% of that of Hf. Decrease is small over the core life.

**Corrosion**—Good resistance.

**Mechanical properties**—Sufficient yield strength to resist scramming loads of PWR control rods.

**Irradiation damage**—There is no change in appearance, and mechanical strength *improves* with irradiation.

**Fabrication**—Melting, forging, extrusion and machining are performed readily.

The alloy would be preferred to hafnium because of the greater availability and lower cost of raw materials and the lower fabrication cost (*1*). It is definitely preferred to boron–stainless-steel alloy because the latter is subject to severe irradiation damage (*2*).

Binary silver-cadmium alloys were early investigated as control materials for PWR's. Although these alloys offer some of the advantages listed (*3*), they have two drawbacks: corrosion resistance is poor in high-temperature water, and neutron-absorption characteristics are initially too low and fall off rapidly under irradiation.

To correct these disadvantages, a ternary alloy of silver and cadmium was sought. Of the possible additives, mercury, boron, gold and hafnium were discounted for reasons including toxicity, radiation damage and high cost. Indium was selected since it provides an alloy of suitable metallurgical, neutron-absorption and corrosion (*4–6*) properties.

## Neutron Capture

As a poison for the ternary alloy (Table 1), In compares favorably with Hf. Its resonant neutron-absorption

* Pressurized water reactor is used here generically. Although this material is being considered for replacement control rods for Shippingport, no decision is expected on this until the first core is actually replaced.

peaks are somewhat poorer than those of Hf but complement well those of Ag. The In thermal-neutron cross section is larger than that of Hf.

The most effective Ag-In composition, from the standpoint of neutron absorption, would appear to be equal atomic densities of Ag and In. However, the solubility limit of In in Ag is 20 at%. Thus, Cd is required to raise the thermal cross section and In is decreased below 20 at% to maintain a single-phase alloy while accommodating the Cd.

Table 2 compares the neutron-absorption effectiveness of Ag alloys with that of Hf. Alloy 2533 is the initial composition, and 2115 simulates the composition after exposure to a flux of $10^{14}$ n/cm²/sec for 3,000 hr (the low-cross-section isotope of Cd formed by transmutation of Cd and $Cd^{113}$ burnout was replaced by Sn to obtain a clearer picture of loss of neutron-capture effectiveness). During irradiation, Ag transmutes to Cd, In to Sn and Cd remains as an isotope. The transmutation products all have low neutron-absorption cross sections. Thus, the neutron-capture value would be expected to decrease about 5%, as indicated in Table 2.

In actual PWR operation, the average neutron flux to which the control rods are exposed should be considerably less than $10^{14}$ n/cm²/sec, and therefore the transmutation of alloy constituents should be correspondingly less. Also,

**TABLE 1—Neutron Absorption Properties of Several Poison Elements** (7)

| *Element* | *Thermal (2,200 m/sec) cross section (barns)* | *Important absorption peaks (ev)* |
|---|---|---|
| Cadmium | 2,550 | |
| Indium | 198 | 1.46, 3.86, 9.10 |
| Silver | 62 | 5.12, 16.60 |
| Hafnium | 105 | 1.08, 2.36, 5.9 6.6, 7.8, 8.8 |

**TABLE 2—Neutron-Capture Worth of Ag-Base Alloys**

| *Alloy No.* | *Composition (wt%) Ag* | *In* | *Cd* | *Sn* | *Relative worth* |
|---|---|---|---|---|---|
| Hafnium | | | | | 1.00 |
| 2533 | 81.6 | 13.6 | 4.9 | | 0.99 |
| 2115 | 77.2 | 11.1 | 0.79 | 10.8 | 0.94 |


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the loss of neutron-capture effectiveness should occur at a decreasing rate once the high-cross-section $Cd^{113}$ is consumed.

### Corrosion Behavior

In 600° F static neutral water, alloy 2533 has good corrosion resistance with a penetration rate of 0.18 mil/yr. There is a weight gain due to internal oxidation of In. Increasing the Cd content much beyond 5 wt% results in a weight loss and an undesirable corrosion rate.

Alloy 2533 was subsequently tested under a variety of conditions. Figure 1 indicates the low corrosion rate displayed at all temperatures in degassed and hydrogenated water, neutral and high-*p*H water and static and dynamic water. Increasing test temperature or water velocity increases the initial weight gains without greatly affecting the ultimate corrosion rate.

Also shown in Fig. 1 are results for alloy 2567, which simulates alloy 2533 after exposure for 3,000 hr at $10^{14}$ n/cm²/sec. According to the extremely low postirradiation corrosion rate, even at 650° F Sn apparently has a beneficial effect.

In oxygenated water, both alloys lose weight rapidly. However, oxygen contamination of PWR water could only result from an accident. Such a condition would persist for only a few days, at most, before corrective action is taken. While such exposure does not lead to material deterioration, the activity release is considered serious enough to warrant protecting the rod against oxygenated water by electroplating with nickel.

### Mechanical Properties

The minimum yield strength (0.2% offset) required of PWR control rods to resist scramming loads has been calculated to be about 4,000 psi at 600° F. To provide a safety factor, 10,000-psi yield strength combined with a 30% area reduction is considered desirable.

A single-phase, face-centered-cubic crystal structure of the alloy is optimum for metallurgical stability. Laboratory samples have demonstrated that alloy 2533 has the desired microstructure as well as yield strength. The alloys display high ductility, so that deterioration of this property is no cause for concern.

To verify sample results on a full-scale basis, PWR control rods were fabricated by extrusion at 900°–1,100° F from forged and machined billets with a nominal composition of Ag-15 wt% In-5 wt% Cd (similar to alloy 2533), 5.45-in. diameter by 15 in. long. A representative extrusion is shown in Fig. 2. After annealing for 1 hr at 750° F to recrystallize the structure, tensile samples displayed an 11,000-psi yield strength, a 42,900-psi ultimate strength, a 55% area reduction and an elongation in 2 in. of 51%. The corresponding properties at 600° F were 11,000-psi yield strength, 16,100-psi ultimate strength, 71% area reduction and 50% elongation.

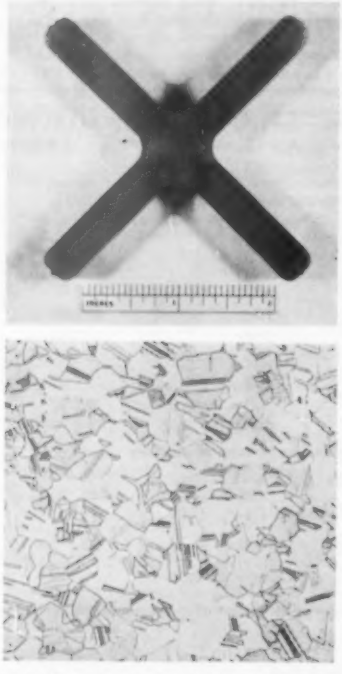


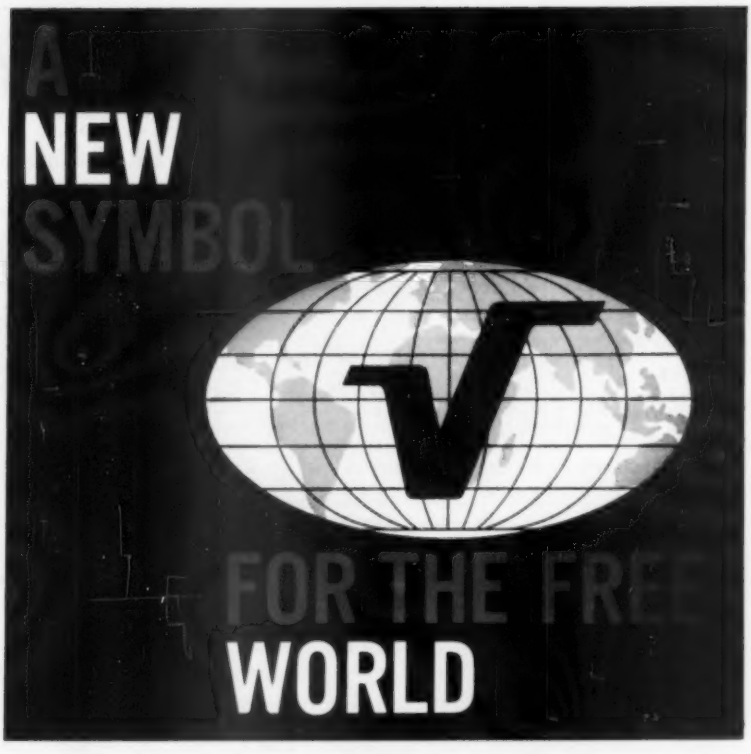
FIG. 2. Extruded Ag-14.7 wt% In-5.4 wt% Cd PWR control rod. At left is cross section of extruded cruciform rod. At right is microstructure (100 ×) of extruded and annealed rod (annealed at 400° C for 1 hr, ASTM grain size 4–6, hardness 80 DPH)

Neutron-capture determinations on full-size rods have indicated that they are equivalent to HF. Corrosion samples from full-size rods indicated no adverse effects at all test temperatures.

Physical properties of this material are listed in Table 3.

## Radiation Effects

Samples (Ag-15 wt% In-4.8 wt% Cd) welded between Zircaloy-2 half-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| OUTPUT POLARITY | pos. or neg. | pos. or neg. | pos. or neg. | pos. or neg. | pos. or neg. | pos. or neg. |
| REGULATION VS. LINE | .03% max. from 100 to 130 volts | .03% max. from 100 to 130 volts | .01% max. from 100 to 130 volts | .01% max. from 100 to 130 volts | .01% max. for 20% line change | .01% max. from 100 to 130 volts |
| REGULATION VS. LOAD | .03% no load to full load | .03% no load to full load | .01% max. for 2 ma change | .01% max. for 2 ma change | .005% for 10 ma change | .01% max. no load to full load |
| STABILITY | .02% per hour | .01% per hour | .005% per hour | .005% per hour | .005% per hour | .005% per hour |
| RESOLUTION | 100 mv at any output voltage | 100 mv at any output voltage | 100 mv at any output voltage | 100 mv at any output voltage | 10 mv at any output voltage | 100 mv at any output voltage |
| CALIBRATION ACCURACY | 2% | 1% | Better than 1% | Better than 1% | Better than .5% | 1% |
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*This article starts on page 122*


cylinders were irradiated in the Materials Testing Reactor to a maximum unperturbed exposure of $1.4 \times 10^{21}$ nvt thermal. The maximum irradiation temperature was estimated at $<392°$ F. No changes were observed in appearance, dimensions or density.

**Metallography.** No changes were observed in the microstructures of irradiated samples. The amount of Sn produced was apparently not sufficient to exceed the solid solubility limit. No evidence of a second phase was detected, even on the surface layers of this alloy, where a majority of the neutrons would have been absorbed.

TABLE 3—Physical Properties of Nominal Ag-15 wt% In-5 wt% Cd Alloy

Thermal conductivity

| *temp.* (°C) | *cal/sec/cm/°C* |
|---|---|
| 0* | 0.131 |
| 25* | 0.135 |
| 50 | 0.141 |
| 100 | 0.150 |
| 200 | 0.168 |
| 300 | 0.183 |
| 400 | 0.196 |
| 500 | 0.207 |
| 600 | 0.216 |

Dynamic modulus of elasticity

| *temp.* (°C) | $lb/in^2 \times 10^6$ |
|---|---|
| 25 | 11.52 |
| 100 | 11.13 |
| 200 | 10.62 |
| 300 | 9.86 |
| 316 | 9.68 |

Linear coefficient of thermal expansion

| *temp.* (°C) | *in./in./°C* |
|---|---|
| 25–500 | $22.5 \times 10^{-6}$ |

Density

10.17 gm/cm³ at 25° C

Melting range

775° to 825° C (approx.)

* Extrapolated.

**Mechanical properties.** Although the surface layers are expected to receive the most radiation damage, a hardness traverse on an irradiated specimen indicated no difference between the surface and the interior.

Irradiation increased slightly the tensile strength and lowered slightly the ductility. The 0.2% offset yield strength increased from 8,400 psi to a maximum of 27,900 psi. The largest changes occurred in the samples of lowest exposure. It seems likely that

the yield-strength increase is caused by Sn formation rather than by formation of a second phase.

The highest-exposure samples indicated the least increase in strength. These exposures would have occurred at higher temperatures, the hardening effects thus being partially annealed out.

**Corrosion effects.** Based on short-term data, it appears that irradiation does not affect the corrosion resistance of Ag-In-Cd alloys.

* * *

*This article is based on a paper sponsored by the American Institute of Mining and Metallurgical Engineers for presentation at the 3rd Nuclear Engineering and Science Conference in Chicago, March 17–21, 1958.*

*The authors are indebted to B. Lustman, Manager of the Metallurgy Subdivision of the PWR Project, for his considerable assistance and guidance during the course of this work. Acknowledgment is made to Wm. Haynes, R. Haffeman and R. Tombaugh of the Nuclear Core Engineering Dept. for their efforts in designing, tooling and following the fabrication of full size control rods, to S. Paprocki of Battelle Memorial Institute for the thermal-conductivity measurements and to R. Roese of Bettis for the high-temperature water-corrosion data.*

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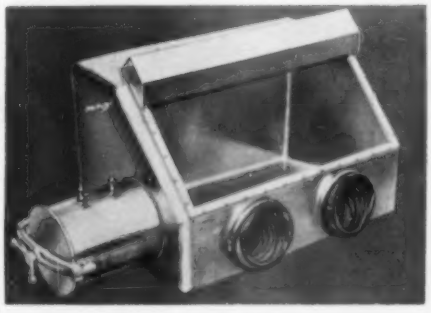

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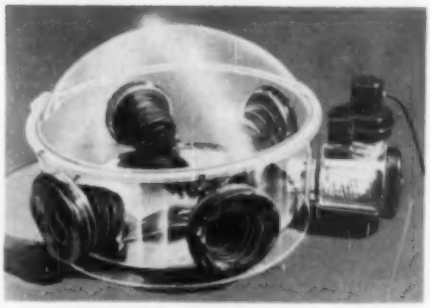

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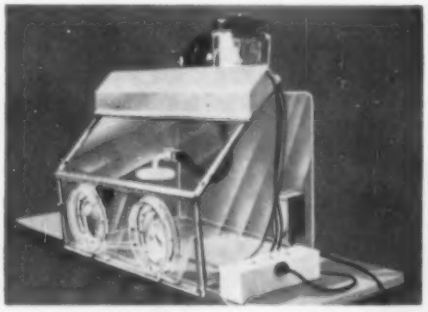

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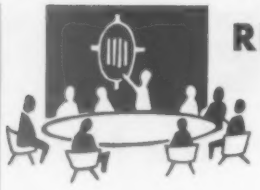

# REACTOR ROUNDTABLE

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## Gaseous-Fuel Reactor

By S. BARON

*Burns and Roe, Inc., New York, New York*

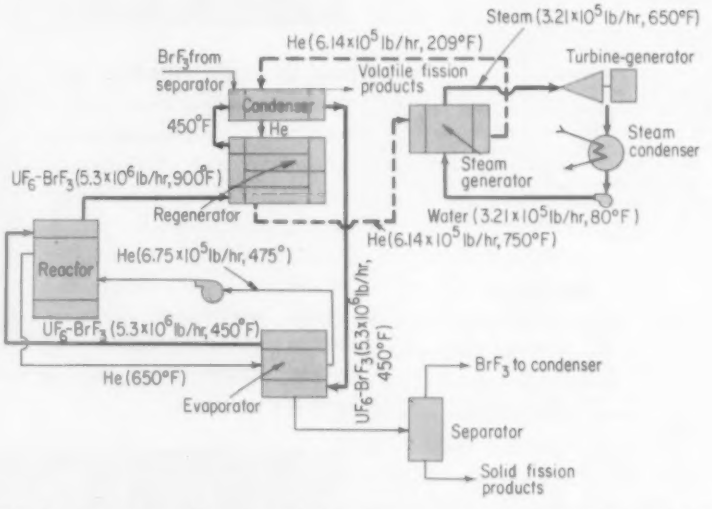



FIG. 1. Flow scheme for gaseous fuel reactor. Heavy solid lines show circuits for $UF_6$ gaseous fuel (with $BrF_3$ additive) and turbine steam. Heavy dotted line represents He gas intermediate coolant circuit

Although many combinations of solid- and liquid-fuel reactors have been proposed, no one, at least in the unclassified literature, has described a reactor that uses fissionable fuel in a gaseous form.* Generally, one would be inclined to eliminate such gas-phase reactors because the fuel concentration would be too low. However, adequate fuel densities can be achieved with some gases at fairly moderate pressures. Uranium hexafluoride (b.p. 64.05° C, 1,134 mm) (*1*), for example, would make a good gaseous fuel since its density is reasonably high at the pressures and temperatures of interest in reactor design. In addition, $UF_6$ is conveniently available and there is a wealth of information on its properties and methods of handling from our gaseous-diffusion isotope-separation experience. Information on the fission-product fluorides that would be formed in such a reactor is available from fuel-element reprocessing by fluoride distillation.

Figure 1 shows a possible flow diagram for a $UF_6$ gas phase reactor. As it flows through tubes piercing a graphite core, the gas is heated internally by fission energy. The gas leaves the reactor at 900° F and enters the regenerator where it gives up its sensible heat to an intermediate helium coolant, which is recycled from the steam generator. The $UF_6$ then condenses at

*Continued on p. 130*

* S. A. Colgate and R. L. Aamodt (NU, Aug. '57, 50) have proposed a fission-plasma reactor that uses $UF_6$ as the fissionable fuel; however, their scheme, which converts fission energy directly into electricity, differs radically from the more conventional reactor design presented here.

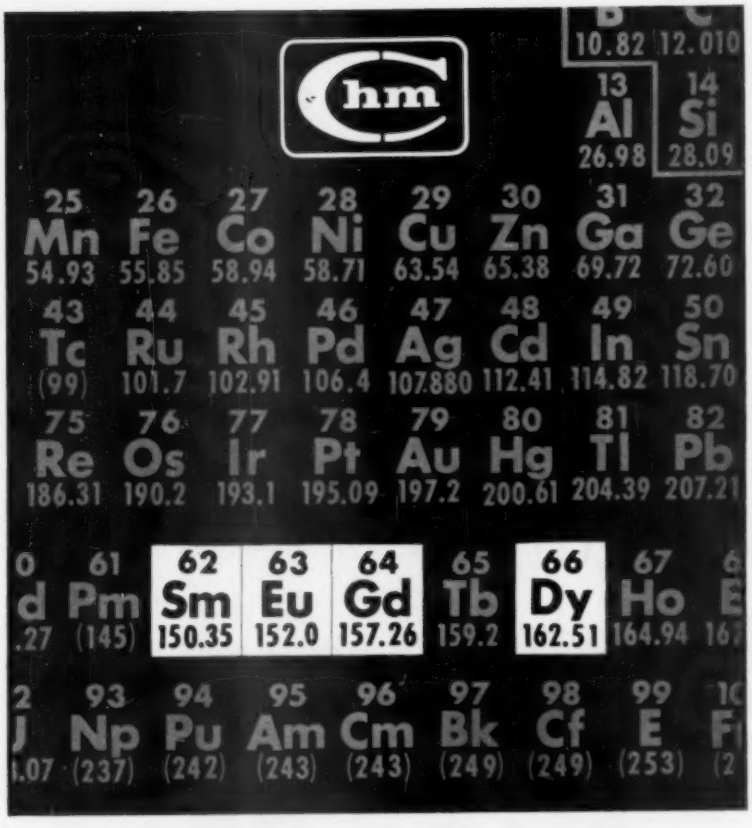
TO THE REACTOR ROUNDTABLE EDITOR:

I have been very much interested by the first article to appear in "Reactor Roundtable" entitled "Temperature-zoned Reactor" (NU, May '58, 114). The authors mention a possible application to a "Calder Hall" type reactor where a central low-temperature region would be fueled with natural uranium (in magnesium-alloy cans) and a high-temperature annular zone would contain uranium-oxide fuel elements clad with stainless steel. One possible drawback would be that the shape of the neutron flux radial distribution could not be too easily "flattened," except possibly with a two region lattice. But this idea of two independent zones of temperature is certainly very attractive for superheating. (See also NU, Feb. '58, 75 and *Nuclear Power*, May '58, 254.)

It may be of interest to point out that the French dual-purpose G2 and G3 reactors at Marcoule have been designed in 1955 with two zones of temperature. (See, for instance, "Les Centrales Nucleaires" by P. Chambadal, Armand Colin, Paris 1957, pp. 128–132).

These reactors are cooled by carbon dioxide (at 15 atm), graphite moderated and fueled with natural-uranium rods with magnesium cladding. The inlet gas temperature in the central zone is only 70° C to obtain a relatively high maximum specific power (around 4 Mw/ton) without too high an internal uranium temperature (550° C). In the external region with a lower flux, the can surface temperature is limited to 400° C and a higher inlet gas temperature (150° C) is now possible. The gas flow is approximately equally divided between these two zones: 20% of the exit gas flow at 335° C superheats the steam (up to 10 atm and 315° C) while the remaining 80% at 290° C is used for preheating and boiling (in two types of boilers with different pressures). Part of the low-pressure steam drives turboblowers for $CO_2$ pumping (7 Mw) while the rest drives a 28 Mw turbogenerator. The two entrance regions are fed by two different $CO_2$ blowers at approximately the same pressure. A single inlet temperature with gas mixing at the outlet would have given a much poorer over-all efficiency.

—GILBERT B. MELESE
*Assistant Professor*
*Columbia University*
*New York, New York*

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*This article starts on page 128*

450° F in the condenser section, giving up its latent heat to the helium. From there the $UF_6$ liquid passes to the evaporator, where it is vaporized at 450° F and returned to the core.

In this first design, rather than tackle the problems of developing a suitable compressor, the flow would be provided by natural circulation. Likewise the intermediate He-coolant circuit avoids the problems of radioactive leaks into the steam side or the development of a direct-cycle turbine capable of handling the radioactive $UF_6$. Eventually when experience allows, these stopgaps could be removed to give improved efficiency and costs.

Generally, the advantages of a $UF_6$ gas-phase reactor would be similar to those of other homogeneous reactors. Thermodynamically, a gas-phase reactor produces superheated steam at temperatures higher than the water-type reactors, but not as high as the liquid-metal type.

Since the uranium is also handled in the form of $UF_6$ in the diffusion plants and fission products and Pu can be continuously removed during operation, fuel reprocessing is simpler even than other homogeneous reactors. The large negative temperature coefficient associated with the gaseous fuel density should make the reactor both very easy to control and inherently safe.

The major disadvantage in this reactor type is the poor heat-transfer characteristics of the gaseous fuel, which results in a high holdup of fuel and large heat-exchanger surfaces. Experimental data are required to determine more reliable heat-transfer coefficients for $UF_6$ gas.

Corrosion and stability studies are still required to determine the extent of the fluoride attack on the structure materials and their stability in the high radiation field. Preliminary evidence would indicate a reasonably stable system, with aluminum as a satisfactory material for resisting fluoride corrosion in the reactor. As in all circulating homogeneous reactors, delayed neutrons induce activity in the heat exchanger and there is a holdup of fissionable material in the external circuit.

## Reactor Physics

Since in this reactor the gaseous fuel is also the heat-removal medium, the fuel-to-moderator ratio determines not only the critical core size but also the

total reactor power. With a fixed core-tube design and fuel enrichment, modified one-group, two-region calculations were first made to find the graphite-to-fuel ratio that would give the highest $k_\infty$ (minimum core size). As shown in Fig. 2, this ratio lies between $50 \times 10^{-6}$ to $80 \times 10^{-6}$ atomic ratio of uranium to graphite.

This optimum results from the opposing effects of decreasing thermal utilization and increasing resonance escape, as the atomic ratio of graphite to uranium increases. The values compare favorably with the optimums calculated for solid-uranium graphite-moderated reactors (*2*).

However, a reactor with such a dilute fuel content would produce insufficient power. To get a reasonable power the fuel content must be increased above the minimum-size value which means a larger reactor.

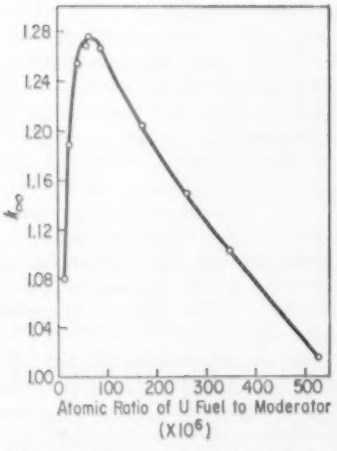


FIG. 2. Infinite multiplication constant $k_\infty$ as a function of atomic ratio of U and graphite for fixed enrichment of U

If the core diameter is held at 7.5 ft, the use of a fuel-to-graphite ratio greater than the optimum requires a higher enrichment than that used for Fig. 2. The enrichment requirements increase rapidly with the higher power output so that the cost of $U^{235}$ inventory held up in the heat exchangers can quickly become exceptionally high.

With a reactor core 7.5 ft in diameter and a fuel volume of 20%, the $U^{235}$ enrichment requirement is 8%. The fuel inventory for this natural circulating circuit design based on $40 per kg natural uranium and $15 per gm for fully enriched uranium would be about $4½ million. Forced-circulation design, if practical, would probably reduce the inventory cost to about $3 million.

## Engineering Design

The critical temperature and pressure of $UF_6$ are 250° C and 45 atmospheres (*1*), respectively. By operating at a boiling temperature of 450° F, the vapor pressure of $UF_6$ would be 33.4 atmospheres and the liquid density 1.63 gm/cm³ (*1*). The saturated vapor becomes superheated to 900° F in passing through the reactor.

**Materials.** Aluminum and nickel are good structural materials in resisting fluoride corrosion at high temperatures (up to 1,100° F), whereas iron is suitable for temperatures up to 500° F (*3*). Of these materials, aluminum is best suited for reactor use because of its low neutron absorption. However, its low strength at high temperatures limits its application as a structural material at temperatures above 700° F (*4*).

Nickel and its alloys are satisfactory for the high-temperature nonreactor components such as piping, valves, fittings, and heat-exchanger tubes. Steel can be used for the low-temperature shells of the reactor and heat exchangers. Carbon or graphite reacts with fluorides only after heating (*1*), so that either could be applied satisfactorily as a reactor moderator.

**Core-tube design.** To allow operation as close as possible to the temperature limit, a aluminum double tube wall construction was adopted for the core channels. The $UF_6$ gas would flow inside the aluminum tubes with helium-gas coolant in the annulus between the double tubes.

By maintaining the helium pressure at a value slightly below the $UF_6$ gas pressure inside the inner tube, the pressure difference would be small enough to contain the high temperature gas without rupture.

With a $UF_6$ gas pressure of 30 atmospheres, a helium pressure of 28 atmospheres and reasonable gas velocities, a 900° F $UF_6$ gas temperature and 650° F helium temperature would give a maximum wall temperature of about 715° F. Gas-phase corrosion studies at 650–750° F with halogen fluorides and fluorine promise very little attack on the aluminum walls (*5*).

**Mass flow.** The mass flow rate of the gas is a function of its density, velocity and flow area. The density is fixed by the selected temperature (max 900° F) and pressure (30 atm). The velocity is dependent on the design of the natural-circulation circuit. The


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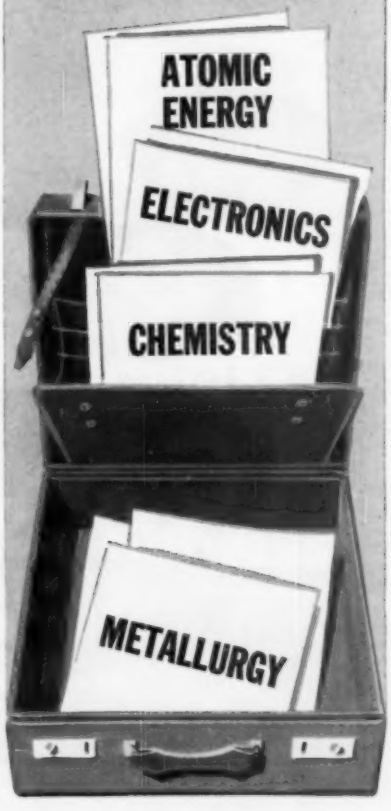


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greater the static height of the liquid leg between the condenser and evaporator, the higher the pressure drop losses that can be tolerated in the overall circuit. However, structural considerations limit the magnitude of the elevation. A static height of 25 ft was found to be satisfactory for producing a reasonably high circulation rate.

**Reflector.** A graphite reflector about 3.5 ft thick is equivalent to an infinite reflector in the critical-size calculations. With a 7.5-ft core, the total reactor diameter with the reflector would be 14.5 ft. The double-walled aluminum tubes are set within the graphite moderator blocks so that the full pressure of the helium (28 atm) can be contained by the graphite, which has a tensile strength of about 3,100 psi (*3*). In such a design, the reactor shell acts as a container, not as a pressure vessel. The outer aluminum tube would serve not only as a secondary partition between the graphite and the fluorides, but would also prevent the helium gas from eroding the graphite.

If distortion of the graphite resulting from radiation damage and thermal effects makes this scheme impractical the reactor shell can be designed to hold the gas pressure. The design requirements for a 14.5 ft diameter shell at 28 atm is within present fabrication technology.

**Fuel decomposition.** Although little decomposition in the radiation field is anticipated for $UF_6$ (*3*), a strong fluorinating agent such as $BrF_3$ (b.p. 127° C) (*6*) can be added to the $UF_6$ to minimize what decomposition does occur. Fluorine might also be used, but would be difficult to separate from the gaseous fission products such as xenon and krypton. Its subsequent recycling would pose a problem. About 10 mol% $BrF_3$ should keep fluoride decomposition at a negligible level.

Assuming that $UF_6$-$BrF_3$ behaves in accordance with Raoult's law, 10 mol% $BrF_3$ in the gas when it condenses would produce 20 mol% $BrF_3$ in the condensate. The additional requirements for $BrF_3$ are met by recycling the excess drawn off the evaporator which is producing 10 mol% $BrF_3$ in the vapor. Part of the $BrF_3$ then is recycled between the evaporator and the condenser.

**Heat exchangers.** If enough surface is designed into the reactor core, the helium coolant in the annulus can

pick up enough heat to supply the evaporator. A design using 20% fuel volume with a 2-pass flow has just about enough surface used to recover the heat needed to evaporate the circulating fuel.

The regenerator would have the greatest heat load of all the heat exchangers, and the poorest heat-transfer coefficient because of the gas-to-gas system. A four-pass design is used to balance the requirements for large surface and high velocity, using rather small nickel tubes (½-in. diameter) for all the heat exchangers would permit a large surface-to-volume design with some improvement in the $UF_6$-$BrF_3$ heat-transfer coefficient.

With the fuel in the liquid phase in the evaporator, the inventory of fuel would be very large if the heat transfer were poor. Therefore, the liquid velocity was kept as high as possible without excessive pressure drop.

**Net output.** The generator output for this particular design and fuel flow rate would be 35,000 kw. The auxiliary power requirements (mostly to circulate helium in the various pieces of equipment) are somewhat higher than those of non-gas-cooled reactors. About 5,000 kw would be required for the helium compressors, circulating water pumps, condensate pumps, and other miscellaneous plant electrical loads. The net available power would then be 30,000 kw.

## Fuel Reprocessing

During operation both fission products and Pu would be formed in the $UF_6$ gas. Because of the strong fluorine atmosphere, the Pu and all of the fission products except the inert gases would be expected to form fluorides. Those fluorides more volatile than $UF_6$ can be vented off along with the inert gases during the liquid phase of the coolant cycle. Pu and most of the remaining fission-product fluorides (except for $Te_2F_{10}$)* happen to be solids under the proposed conditions. These can most likely be removed by filtering liquid $BrF_3$ from the evaporator and recycling it to the condenser.

It would appear then, at least under ideal conditions, that Pu and fission products can be removed and partially separated in this reactor design. The uranium, of course, is continuously depleted as it circulates between the reactor and heat exchangers. The enrichment of the fuel can be maintained simply by removing a stream periodically, and shipping it to one of the $UF_6$ isotope-separation plants. The reprocessing of the fuel is simply a matter of adding the fuel to one stage of the plant and removing it, with a higher enrichment, at another stage.

* * *

*The author wishes to express grateful appreciation to A. G. Taecker, Director of the International School of Nuclear Science and Engineering, and his faculty, particularly, J. J. Katz, H. H. Hyman, F. G. Prohammer and J. T. Weills, for review and helpful suggestions in the preparation of this paper. The material for this paper was initiated during the project work by the author at the International School of Nuclear Science. Miss Ada Chin of Burns and Roe was very helpful in assisting in the physics calculations and studying effects of some of the variables.*

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* $Te_2F_{10}$ separation from $UF_6$ would not be easy, but it is not readily formed (7). Pilot plant experience in separating volatile fluorides by fractional distillation has indicated that Te-U separation was feasible (8).

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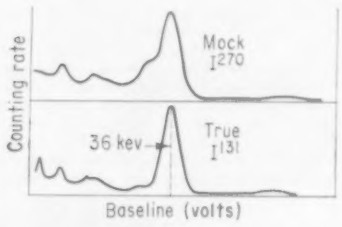
6

# APPLIED RADIATION

## Mock Iodine for $I^{131}$ Calibrations

Calibrating equipment designed to count 8-day $I^{131}$ is difficult in view of the inconveniently short half-life of the nuclide. A useful simplification is available in Marshall Brucer's "mock iodine." This is a mixture of 8-year $Ba^{133}$ and 30-year $Cs^{137}$ combined with special absorbers. The resulting gamma spectrum is like that of $I^{131}$, and the useful life is about 10 years.

Brucer originally developed the sources at the Medical Division of the Oak Ridge Institute of Nuclear Studies. They were included in the "thyroids" of phantoms that were sent to different laboratories to test their $I^{131}$ counting procedures. The inventor has recently received a patent on the manufacture, and meanwhile the sources have become commercially available.




**Mock-iodine and $I^{131}$ spectra look like this when counted with 2-volt channel width in a NaI well crystal. Largest $I^{131}$ peak is at a 37-volt baseline**

The figure shows the spectra from a true $I^{131}$ source and a simulated source produced and sold by the New England Nuclear Co. In view of the different half-lives of the two radioactive components, the shape of the spectrum can be expected to change somewhat with time. However, since the ratio of barium to cesium can be from 5.7 to 14, the shape remains satisfactory for calibration purposes for a long time. New England Nuclear makes two standard mock iodine sources available—a 0.03-$\mu$c source for $45 and a 3.0 $\mu$c source for $50.

Brucer indicates that 4 or 5 companies are now making mock iodine. The former name, "$I^{270}$," has been dropped to avoid confusion. He emphasizes that it does not pretend to be iodine. Rather it is a handy calibration aid to have around if you know how to use it.

## Neutron Gaging for Waveguide Plating

How thick is the silver plating on the inside of a brass waveguide? If it is too thin, the wall has low conductivity, and the guide has high loss. If it is too thick, critical dimensions are changed, and cutoff wavelength is shortened. But how do you measure a thickness of 1–10 ten-thousandths of an inch in the middle of a 3-ft length of guide that has a 1 × 0.5-in. cross section?

Armour Research Foundation activates $Ag^{107}$ and $Ag^{109}$ with neutrons from a 200-mc Ra-Be source and counts the betas from them with a special counter that slides inside the guide. In a total time of 5 min the method measures plating to $10^{-5}$-in. accuracy. It was first reported some time ago* and has been further developed recently.

For activation the guide is exposed to the neutron source in a lead-shielded, water-filled tank. Water moderates the fast neutrons, and the thermal flux is at a maximum of ~2,500 n/cm²/sec at the guide—~3 cm from the source.

**Sensitivity.** The two silver isotopes have much larger cross sections for activation than the nuclides in the brass that compete for recognition: $Cu^{63}$, $Cu^{65}$, $Zn^{64}$ and $Zn^{66}$. Activation produces 140-sec $Ag^{108}$ and 24-sec $Ag^{110}$ that emit 1.77 and 2.22-Mev beta particles among other things.

Precise timing and short delays are required to take advantage of the short half-lives and high emission rates of the silver nuclides. A set of relay timers control both neutron irradiation and subsequent counting, each of which requires 140 sec. The relay timing system insures reproducibility from run to run.

Beta absorption in the brass requires a special counter that fits inside the waveguide. It is made of ⅜-in. square tubing with a 1-mil stainless-steel window. The filling is argon with a small amount of alcohol for self-quenching. For the thinnest measurable plating—0.0001 in.—the beta count from the brass is about equal to the silver count. It would be about twice as much were it not for the self-absorption in the brass. This background count can be determined with precision, so it is not much of a problem.

---

* H. V. Watts, C. A. Stone, L. Reiffel, *Proceedings of the National Electronics Conference*, vol. 8 (January, 1953).

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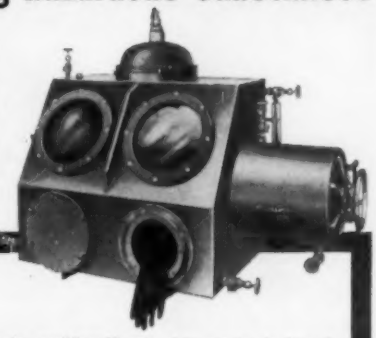

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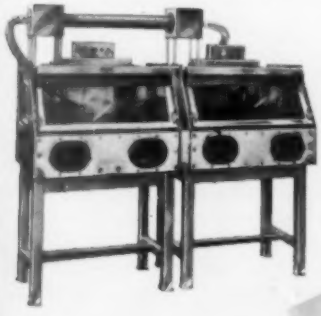

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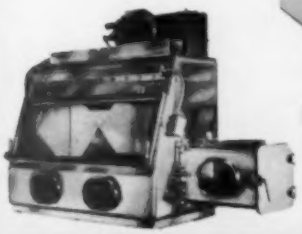

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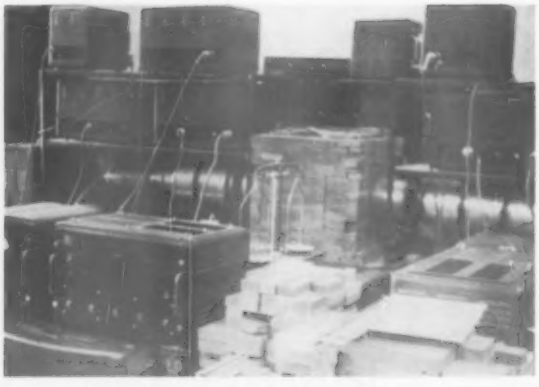
*Recollections of a Russian journey . . .*

STUDENT-FACULTY LUNCHROOM. This is one of several eating facilities of this type that are scattered throughout the buildings of the University of Moscow



LAVISH EQUIPMENT. Three-barreled neutron howitzer is typical of materials used in the university's physics department. Sturdy equipment is made to last

# Radioisotopes in Russia

By HENRY J. GOMBERG
*University of Michigan, Ann Arbor, Michigan*

(EDITOR'S NOTE: *The author and A. O. Allen of Brookhaven National Laboratory were among 70 non-Russians invited to the All Union Conference on Application of Radioactive and Stable Isotopes in the National Economy and Science in Moscow, April 3–15, 1957. A. Hollaender of Oak Ridge National Laboratory was also invited from the U. S., but he did not attend. The following are some recollections of the author's Russian visit.*)

IN RESPONSE TO A CABLED INVITATION received about March 12, 1957, I traveled to Moscow for a meeting on isotopes sponsored by the Akademy Nauk of the U. S. S. R. There Dr. A. O. Allen of Brookhaven and I met for the first time.

The invitation did not specify any special topic of interest but did offer the opportunity to present papers of one's own choosing. On arrival in Moscow, I learned that one major reason for my invitation was interest in the work we had pursued in two areas. The first was radiobiology, in particular the effects of radiation on parasites. The second was work in high-resolution autoradiography. For my part, I was interested not only in these research areas but also in exchanging ideas on training in the field of nuclear energy and on construction and use of training and research reactors.

The criteria by which the progress of others is judged often involves comparison with one's own status. This requires the existence of standards of achievement which both groups can accept. In some aspects of radiobiology, there appears to be an impasse which leaves us wondering whether one or the other group is "all right" or "all wrong."

I was not particularly prepared for what I heard and observed. The terminology, experimental techniques and results left me rather puzzled since, within my limited knowledge of the field, I had not come across anything like this. Broadly speaking, it is believed in the West that the mammalian nervous system as a whole is fairly resistant to radiation. No gross changes are observed and no marked changes in behavior pattern appear up through dose levels which are known to produce some recognizable physiological changes.

## Unlike us, the Russians find the nervous system highly sensitive to radiation

The Russians, on the other hand, believe the nervous system is the most sensitive to radiation. Referring to this conflict, Prof. Ukolova of Rostov on the Don, speaking as a "commentator" or reviewer after a session on radiation effects in higher organisms stated, "The question of the high radiation sensitivity of the higher nervous system is closed; it exists." He went on to say that if there were no sensitivity of the higher nervous system to external influence, there would be no explanation of adaptation to adverse conditions—a doctrine to which the Russians are devoted. He pointed out that many of the experiments reported showed changes in specific organs which could be attributed solely to changes brought on by damage to the higher nervous system. The changes in body organs were in response to damage to the higher nervous system, not due to direct effect of the radiation.

Prof. Michaelov, another reviewer, launched a surprisingly violent attack on a Dr. Alexandrovskaya and

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others who in their studies of radiation effects had studied morphologic changes in the internal organs and neglected to make measurements which had significance in the Pavlovian scheme of body type analysis.

There were many papers reporting on disturbances in the higher nervous system in which effects clearly definable in a Pavlovian sense were observed. Among other things, it was claimed that response to radiation varies with the "nervous" type as classified by Pavlov.

As an example, a paper by L. I. Kotlyarevsky and others of the "Institute of Higher Nervous Activity" reported on the difference in effects of radiation in animals with a "balanced nervous system," an "excitable type of nervous system," and "a weak type of nervous system." These effects, however, do not result in gross changes but in altered response to sound, light and other factors used to test Pavlovian response. Interspersed in the papers and discussion were remarks indicating a definite feeling of superiority over western workers who had failed to perceive what was so clear to the Russians.

On returning from the meeting with the usual chauffeur-driven car, I was joined by a Professor H. Woo, a radiologist and specialist in radiobiology from the Medical Research Institute of Shanghai. He had been educated in England and was imbued with western standards of judgment in the scientific area. But, as a delegate from Communist China, it may be assumed that he at least accepted their political orientation. It was therefore very interesting for me to hear him express very serious doubts and reservations on the scientific value of the Pavlovian scales and criteria as applied in the area of radiation biology.

### The situation reminds me of the Lysenko affair that broke so unpleasantly

My reactions of doubt and misgiving, tempered by a "wait and see" feeling, are much like the reactions many of us had to the Lysenko affair which broke so unpleasantly in the recent past and which will haunt Soviet geneticists for many years to come. Here too there was a doctrine to be followed and deviation was treated rather harshly.

However, the higher nervous system

is by no means the only area in radiation biology which is under study. An apparently new group has been organized under Professor M. N. Meisel as an Institute of Microbiology. Reports from his group and from the Institute of Biophysics left the impression that although the work was fairly new (1956), they were well on their way in technique and basic research. The papers, in terminology, approach and philosophy could well have come from a top-flight western laboratory.

At this point I would venture an observation and a possible prediction. In the area of effect of radiation on organisms with "higher nervous systems," the work and approach is alien to our thinking. In the area of microbiology and biophysics, the work is completely compatible with ours. At some point these groups are going to work on the same problem, but their results are going to be incompatible. It will be interesting to watch the resolution of the differences between a well established group of the Academy such as the "Institute of Higher Nervous Activity" and these relatively new ones.

### Complete knowledge of our work contrasts with our ignorance of work in the USSR

At the Laboratory of Helminthology (the study of parasitic worms) of the A. N. Bakh Institute of Biochemistry, I met with Professor N. P. Schikobolova and Dr. J. L. Schechtman of the Institute of Biophysics. Working together and with the help of several other investigators they had launched an intensive program of study of the effect of radiation on parasites. In particular, they had checked in less than one year all the work we (Gould, Villella and Gomberg) had published in over six years on the use and effects of radiation on trichinella spiralis.

Fortunately, they confirmed our findings in all cases—in particular, on the difference in the sexual sterilization dose when using 250 kv X-rays and $Co^{60}$ gamma rays. In addition, they were tackling problems which we had discussed but couldn't touch because of lack of manpower and support. We had a long discussion on the technical aspects of the work and speculated on the possible application of radiation as a control measure for food-borne parasitic diseases and in control of nematodes which attack crop plants.

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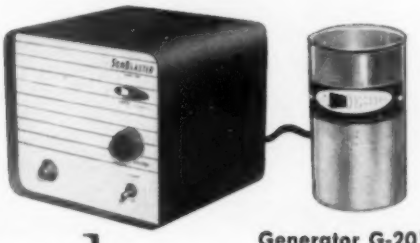

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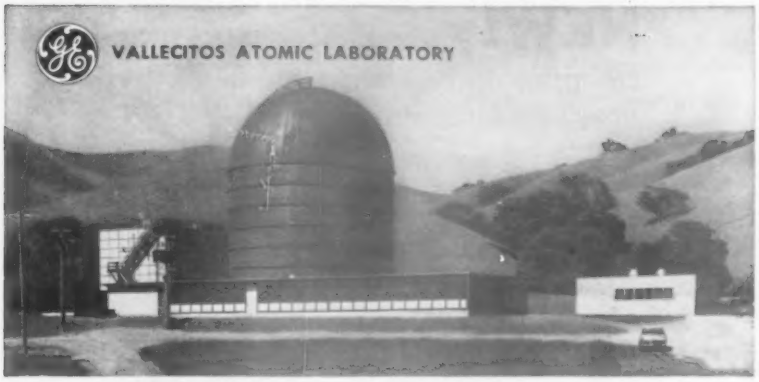


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the complete knowledge of our work which I found as compared to our ignorance of the work going on in the U. S. S. R.

In a completely different area, I spent several very interesting days visiting with my host Prof. Alex Samarin, Deputy Director of the Central Ferrous Metallurgy Research Institute. I offered a review paper on our work in high resolution autoradiography, which was translated by Professor E. V. Borisov, an expert in physical methods of analysis and the developer of a number of X-ray and isotope techniques.

Some index of the degree of leadership this group is providing in Russia can be seen from the fact that from this Institute came the first Russian paper on the use of neutron diffraction for solid state analysis. It was a study of the "superlattice of $NiFe_3$" carried out by a group headed by B. G. Lyashchenko.

**They have well equipped laboratories, and their radiation applications are extensive**

The metallurgy laboratory was extensive and extremely well equipped, primarily with Russian-built instruments of excellent quality. Leningrad appears to be the instrumentation center of the country. At least it was the origin for the optical equipment and electron microscopes I saw.

There is widespread use of radiation and radioisotope techniques not only in the laboratory but also in the field. At the metallurgy sessions, there were many papers devoted to analysis of the dynamics of fluid flow in full-size blast furnaces as determined by tracer experiments. This work has been known to us for some time, and it has raised questions among us on radiation safety. Thus it was interesting to hear, in the discussion period, a vigorous session on the dangers of the indiscriminate use of radioactive materials as opposed to the need to have enough radioactive material present to make significant measurement possible. Here, also, there was complete familiarity with, great respect for, and free reference to work in the United States.

Other highlights of the trip included an excursion to the Atomic Energy Power Plant at Obinskoya where I

became involved in a free-wheeling discussion on safety practices and education for atomic energy work. An attempt by one young engineer to challenge American armaments policy through me was quickly squelched by his colleagues as being irrelevant to our discussions. I also visited the University of Moscow (actually the Lomonosov University) where, for five hours, I discussed the training of nuclear physicists with members of the faculty and where I toured the teaching laboratories in detail. I was given a free hand in taking pictures of the University equipment, a freedom which at one point led to the consternation of a building custodian.

The best word I can use for the laboratory equipment is lavish. Apparently no expense was spared. Here, too, almost all the equipment was Russian. In going through the laboratories, and examining in particular the electronic equipment one observes immediately that the Russians have no use for unnecessary miniaturization. Where it serves a real purpose, as in an airplane, they use it freely. In the research laboratories, strong backs for moving equipment are in order; but the equipment looks as if it will last quite a while.

**Apparently the Russians were not prepared to talk about reactor construction and use**

The University was also the site of a most unsatisfactory meeting which was attempted for discussing reactor construction and use of reactors for teaching and academic research. This meeting, which I requested in my cabled acceptance of the invitation was not in an area covered by the formal conference and apparently was not one in which they were prepared to talk. Much of the good fellowship and courtesy found at the other laboratories was prominently absent here.

Finally, on a more personal basis, when the Russian government acts as your host, the red carpet treatment takes on very special meaning. We lived in a style to which we would love to become accustomed—at home. However, our most precious memory is of a visit to the home of Dr. Samarin where we met his family on the most friendly and intimate personal basis. One truly exotic experience during this visit was drinking vodka and tea and eating pie filled with hardboiled eggs, fish gelatine, rice and lots of pepper!


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## Nuclear Chemical Engineering

**By MANSON BENEDICT and THOMAS H. PIGFORD (McGraw-Hill Book Co., New York, 1957, xiv + 594 pages, $9.50).**

Reviewed by S. LAWROSKI, Argonne National Laboratory, Lemont, Ill.

This book is one of the three volumes in the McGraw-Hill Series in Nuclear Engineering. It is the first book in the nuclear field that has attempted a comprehensive coverage on the chemical engineering aspects of this field. The authors have done a thorough job of reviewing the available literature and have succeeded in preparing an excellent text on the nuclear and chemical engineering problems in the atomic energy field.

This book should be very useful as a reference for those already engaged in the nuclear field as well as a fine text for graduate study. A selection of problems at the end of each chapter aids in understanding the relationships presented.

Three general subjects are presented in the twelve chapters. First, there is an introduction to chemical engineering and nuclear problems in the nuclear field. Next, there is a comprehensive coverage of the over-all fuel cycle from feed materials processing through reprocessing of irradiated fuels. Finally, the separation of isotopes is discussed.

The first two chapters serve as an over-all introduction to the chemical engineering aspects of nuclear power and those aspects of nuclear physics and radiochemistry that are essential to an understanding of the chemical technology associated with nuclear reactors.

Chapters three through eight deal with the over-all fuel cycle. Chapter three outlines the theory of thermal nuclear reactors necessary for calculation of changes in concentration of reactor fuel during irradiation. Chapter four describes the processes for production of uranium feed materials. Chapter five describes the processes for production of the nuclear reactor materials, zirconium, thorium and beryllium. The general principles of solvent-extraction processes for purifying metals are presented in chapter six. In chapter seven, the properties of irradiated fuel are discussed as regards their effect on the various processes proposed for purification of discharged fuel. Chapter eight discusses techniques for reprocessing irradiated fuel from nuclear reactors. Processes discussed include aqueous separations by (1) precipitation, (2) ion exchange, and (3) solvent extraction; and nonaqueous separations by (1) fractional distillation of the fluorides, (2) solvent extraction by liquid metals, (3) extraction with fused salts, (4) vacuum volatilization of molten metals, (5) oxidative slagging, and (6) electrorefining.

In chapters nine to twelve the separation of isotopes is thoroughly presented from both the theoretical and the practical aspects. This presentation is very comprehensive with excellent examples of design principles for both light and heavy isotope separation.

All chapters are well organized and well documented and give a good coverage of subjects to the date of publication.

The chemical engineering problems of radioactive waste disposal have not been discussed by the authors. This could well be included in a future edition of this book.

In brief, this book is highly recommended for anyone, and particularly the chemical engineer, who is interested in the nuclear energy field.

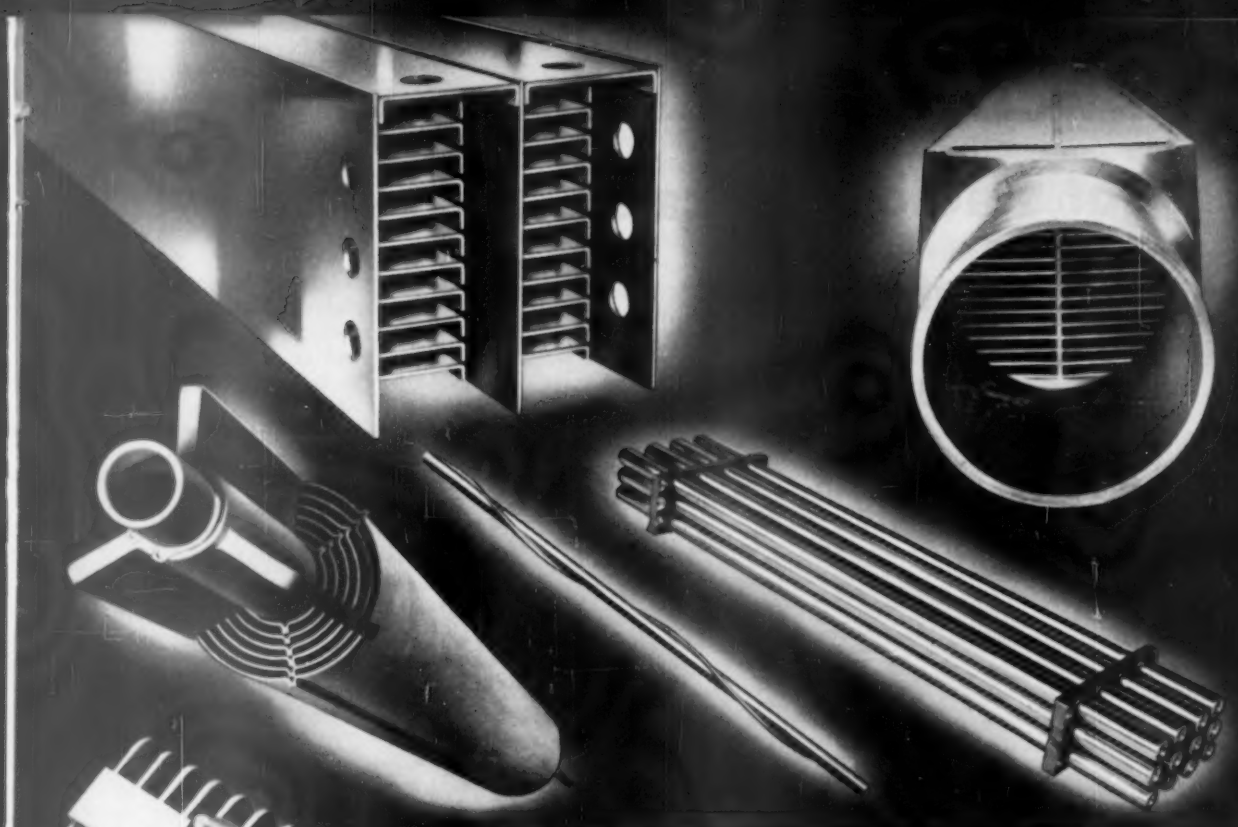
## Ideas, Inventions, and Patents

**By ROBERT A. BUCKLES (John Wiley & Sons, New York, 1957, xv + 270 pages, $5.95).**

Reviewed by ALFONS PUISHES, Registered Professional Engineer and Patent Attorney, Palo Alto, Calif.

The task of presenting a practical work on patent law in one small volume has never been an easy one. To make the subject matter useful to the average reader and still keep it interesting is even harder. In this reviewer's opinion, Mr. Buckles has succeeded on both counts. "Ideas, Inventions, and Patents" not only contains a wealth of practical information but combines a very fine arrangement of subject matter with an easy flowing style that makes the work very readable.

One of the principal objectives of the book is to remove some of the mystery in which patents are often shrouded and thereby correct some of the misunderstanding of patents and other forms of intellectual property held by engineers, scientists and businessmen. Another stated objective is to promote better understanding between the tech-



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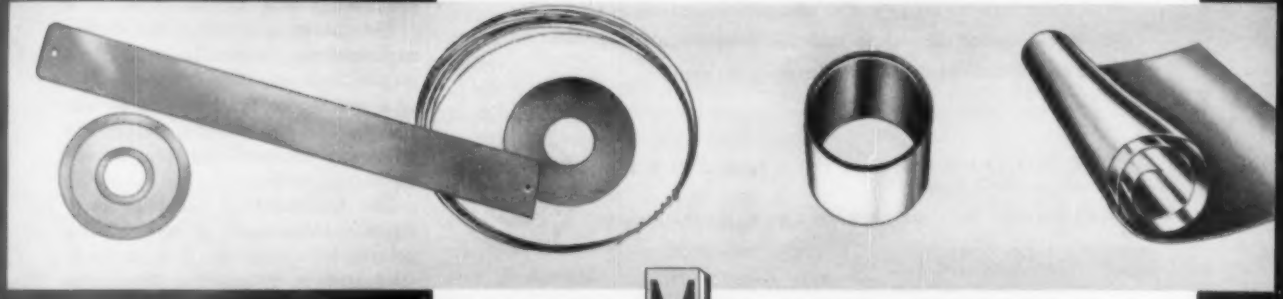

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nologist and the patent attorney. A third important objective is to provide a compact but useful collection of reference material on the subject. The book accomplishes all three of these.

The more broad objective of stimulating the thinking of participants in industry in the field of patents and the motivation of potential inventors is accomplished by a number of excellent examples. These range all the way from some of the earliest historical patents to the later controversial patents of Bell, Edison, Marconi and DeForest and finally to the basic atomic reactor patent of Fermi. The latter, of course, is of considerable importance to all workers in the atomic energy field. Other references to atomic energy are especially gratifying to this reviewer since he has been trying for some time to dispel the apathy with which patents in the atomic energy field are regarded by so many of the participants therein. In the latter respect this book is very timely.

The description of the presentation of an actual application through the patent office is more complete than that usually encountered in works of this type and includes some good examples of how it should *not* be done.

The important and difficult subject of patent claims is treated as amply as a work of this size would permit and should do much to eliminate the reputation of what the author calls "mumbo-jumbo" language that patent claims now enjoy among many inventors.

It is admittedly next to impossible to provide a good coverage of the subject of interference in a work such as this, but the material on this subject succeeds in pointing out to inventors, particularly, the importance of taking proper steps from the time of the original conception of an idea up to and even for a reasonable time after the patent issues.

The glossary of what the author euphemistically refers to as "patent jargon" increases the value of the book as a permanent reference, as do also the many case, statute and patent references, as well as the sample forms.

The treatment of other property rights in ideas should do much to dispel the misconception that seems to exist, even in informed circles on this subject, especially with regard to designs, trademarks and copyrights.

The latter subject is one of the few instances in which it is felt that the book could have been more complete. The subject of copyright is becoming of increasing importance to the technical writer and it is this reviewer's opinion that it merits more than two pages, even in a work of this size.

Another subject that might have been treated more fully is that of the legal rights and duties of the employee inventor and those of his employer, since it appears that well over one-half of all inventors fall within this category. This would have been of especial interest to inventors in the atomic energy field where the inventor is so frequently, directly or indirectly, an employee of some branch of the Federal Government.

With the few rather minor exceptions noted, the subject matter is so well presented that it might tend to encourage some inventors to handle their own patent applications. Nothing, it is felt, could be farther from the author's mind since as a true advocate he must believe in the old cliche that a man who acts as his own attorney has a fool for a client. This reviewer prefers the admonition, "Don't let first-aid take the place of the doctor."

This review may be summed up by one of the literary quotations that adorn the heading of each chapter of the book. This one from Nietzsche: "A man has no ears for that to which experience has given him no access." This book provides considerable access.

## Précis d'Energie Nucléaire, 2nd ed.

**By G. CAHEN and P. TREILLE (Dunod, Paris, 1958, xxiii + 356 pages, 2.800 F).**

Reviewed by GILBERT B. MELESE, Dept. of Mechanical Engineering, Columbia University, New York, N. Y.

This introductory book on nuclear energy is not intended for specialists in any of the many nuclear fields but for scientists or engineers who want to get some background knowledge of the topic if they have to participate in either construction or operation of atomic installations. Were it not for the lack of assigned problems, it could also serve as a textbook for a graduate survey course in atomic energy.

Though both authors are senior naval engineers, engineering is but a small part of the book. Their naval experience only appears in a six-page treatment of propulsion reactors.

Chapters 1 and 2 summarize the main results in modern physics and in nuclear physics. They seem to be too long as a brief introduction for non-nuclear engineers, but too short for self-consistency.

Chapter 3 on reactor theory seems rather short (56 pages) when attempting to treat reactor physics, control, heat removal and "fusion reactors." One might have liked to see a little more than one page for the treatment of heterogeneous reactors when eight pages are devoted to fusion.

Both fissionable and fertile materials, as well as moderators, reflectors, absorbers and coolants, are briefly reviewed in chapter 4 on reactor materials. A few data should be revised, for instance the price of $U^{235}$ (p. 147) and plutonium properties (p. 149). Bismuth is flatly rejected for use in reactors due to $\alpha$-emission (in spite of LMFR). No limitations are set for use of water as a coolant.

Chapter 5 describes several possible types of reactors and gives a few tables of existing reactors or of power reactors being built. The authors seem to forget the feasibility of a thermal breeder ($U^{233}$ + Th). Among the fuels, they could have mentioned Pu alloys. There is only one "detailed" description of a reactor (Saclay's $P_2$), and no description of Calder Hall (or Marcoule's $G_2$) or of EBR.

Chapter 6 on radiation hazards and protection considers shielding and contains a five-page table for decontamination. Chapter 7 on radiation measurements describes several types of instruments for particle detection.

There is a small chapter on nuclear power reactors with an attempt to compare natural versus enriched uranium and a good paragraph on naval propulsion reactors. The last short chapter mentions the various possible uses of radiation and radioisotopes.

In brief, this clear and well documented book with several graphs and tables, makes pleasant reading. However, less than half of it is directly concerned with nuclear power, which could be rather frustrating for a beginner.

We would welcome a third edition that would keep a better balance between the various topics. This book would then be a happy medium between introductory textbooks on nuclear energy, such as Murray's or Stephenson's, and more comprehensive treatments, such as Bonilla's or Glasstone's. It would then justify a translation into English.


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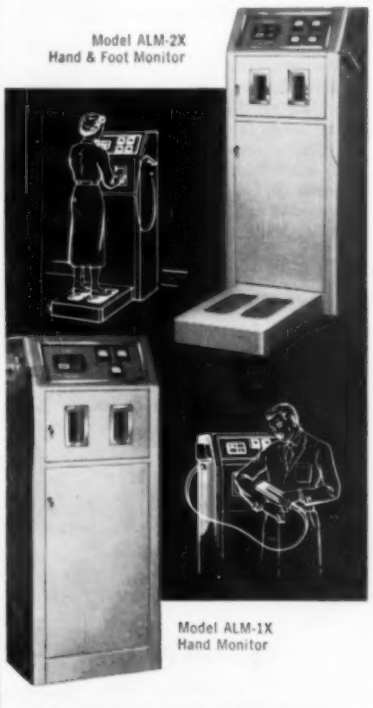

Model ALM-2X
Hand & Foot Monitor

Model ALM-1X
Hand Monitor

In addition to the models shown, T/A also manufactures Hand & Shoe Counters employing the register read-out principle based on Hanford designs.

*Write for Bulletin No. 161*

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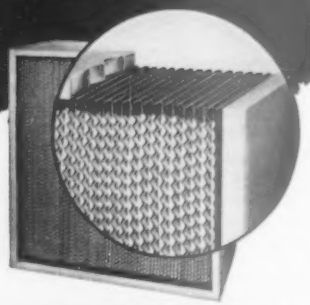

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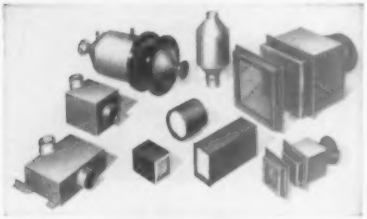
**Write for Bulletin 106C**



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## LETTERS

### Design Makes the Difference

DEAR SIR:

I have read S. Baron's very interesting article "Eight Reactor Types—A Thermodynamic Comparison" (NU, June '58, p. 64).

This comparison is prepared by bringing all the eight reactors to a common parameter. By superimposing these figures, he obtains results that are not in any way a true measure of the performance of the selected types. For example, as Table 1 shows, the efficiency of the Calder Hall Gas Cooled Power Reactor is to be 20.7%. It is true that this figure is taken from operating or design data, but the Calder Hall reactor is designed as a plutonium-producing reactor and the thermodynamic cycle is chosen for a maximum plutonium yield and not for efficient power production.

The English power reactors presently under construction and the AEC gas-cooled power reactor feasibility study, designed for power production, demonstrate a thermal efficiency of 27% or better.

—LAWRENCE PREM
*Nuclear Products-Erco Division of ACF Industries, Inc. Washington, D. C.*

DEAR SIR:

Mr. Prem's comments should be published, as I am sure those concerned with other reactor types would have similar reactions if they arbitrarily look at the comparison without taking into account the basic conditions used in the analysis.

At the time I was preparing the basic data for the thermodynamic comparison of the eight reactor types, which was in early 1957, the only information available in published literature on gas-cooled reactors was that on the Calder Hall installation. With the technology developing so rapidly in the nuclear field, by the time the analysis was completed, and with the usual time necessary for preparation of the manuscript, it was too late to reanalyze the more advanced information on both the English and the U. S. gas-cooled concepts. However, it was apparent to me that these advanced designs would be more efficient than the Calder Hall, and I made reference to this fact in my paper, although the detailed thermodynamic study was not carried out. In all fairness to the other reactor types,

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it could also be said that these have also advanced in steam conditions to varying degrees of improvements in efficiency.

To cite another example, the boiling water type considered for my analysis was that of the 600-psi EBWR. The more advanced designs, such as that of Dresden, are generating steam at 1,000 psi with further improvements in cycle efficiency.

Therefore, any attempt to generalize based on a prepared tabulation would be dangerous if one does not take proper account of the steam conditions considered in the analysis.

—S. BARON
*Technical Director*
*Chemical and Nuclear Department*
*Burns and Roe, Inc.*
*New York, N. Y.*

## Facts of Life—Steel Dept.

DEAR SIR:

As steel suppliers, we are sometimes criticized for failure to produce material of the high "quality" demanded for nuclear applications. We have all had our noses rubbed in the direness of "consequences of failure" so often that I believe there is a tendency to blindly try for the flaw- and defect-free metals we are often asked to produce.

What about an occasional writeup by some practical soul who can present a both-sides-of-the-argument picture? A lot of people have been led to believe that materials are a major bottleneck to progress even in such relatively mild service as pressurized-water reactors.

Even on some of the so-called commercial reactor projects, there are many people of influence who never really had to be concerned about the economic facts of life. Most of their training and know-how was gained on military or AEC projects. Many of the current requirements were born under this aura of "damn the costs, get it done as nearly perfect as possible and by the deadline date."

How far beyond logical service ability and how far towards the letter, if not the spirit, of perfection do we really need to go?

—F. J. Poss
*Pittsburgh, Pa.*

EDITOR'S NOTE: *Mr. Poss describes what we recognize as a very real problem for suppliers to the nuclear industry. Publishing his letter is one mechanism to point it up. However, we hope we can present in a future issue a detailed discussion.*

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PETER M. LANG, *Senior Engineer*
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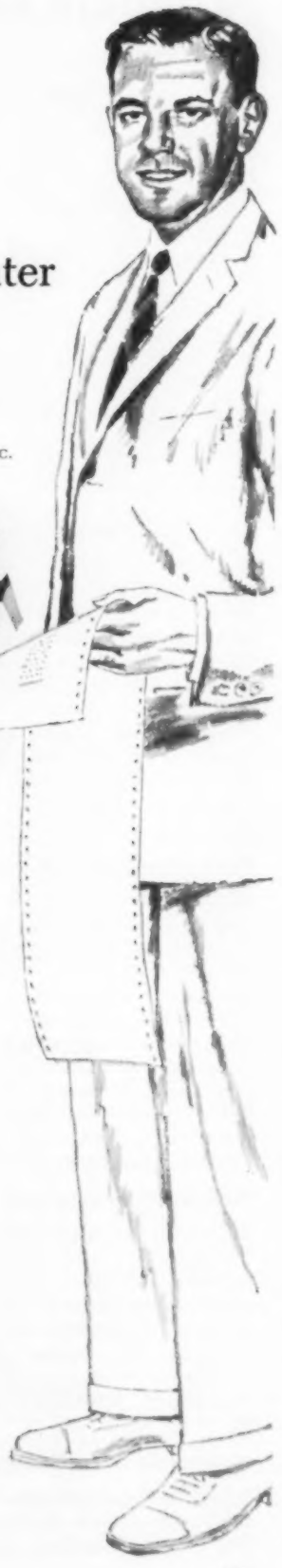

"Our nuclear engineering staff, in developing commercial power reactors, required a full-sized digital computer that the entire group could use. We picked the G-15 and I was first to learn its use. I taught myself in two days without help and in turn taught two-day classes for other ACF employees. Many of us had no previous computer experience, but we are now keeping our G-15 'hopping'—often seven days a week and eight to twelve hours a day."

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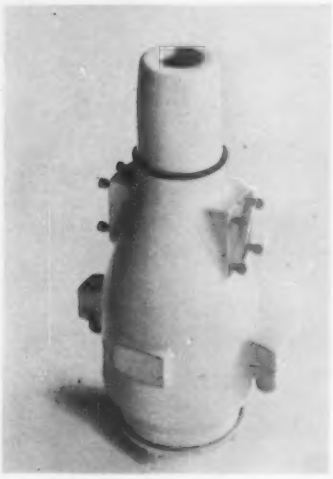
# PRODUCTS AND MATERIALS



## Scintillation Counter Head

Head (above) contains a 1-in.-dia photomultiplier heavily shielded in all directions except for opening to which interchangeable collimators can be fitted. Facilities are also provided for measuring 10-ml liquid samples. It is available either with built-in amplifier to suit existing scalers and ratemeters or with direct output.—Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, Berkshire, England.

## Pulsed Neutron Generator

Model AL 102 consists essentially of vacuum cart containing mechanical forepump and 4-in. mercury diffusion pump on which are mounted ion source and target, high-voltage power supply and electronic control rack. Unit produces neutron yield at target $>6 \times 10^5$ n/sec from D-D reaction and $>6 \times 10^7$ n/sec from D-T reaction. It produces 200-$\mu$sec pulses at repetition rate of 60 cps.—Atomic Laboratories, Inc., 3086 Claremont Ave., Berkeley, Calif.

## Memory Core Analyzer

Model 3303 is 100-channel analyzer having linearity > 0.5%, input counting rates $>10^6$ cpm, cathode-ray-tube data presentation and background subtraction. It accommodates decimal printer or pen recorder.—Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.

## Megacycle Pulse Generator

Model 3450B pulse generator has repetition rates continuously variable from 200 cps to 2 megacycles in five calibrated decade ranges. Secondary emission tubes and fast-recovery-time circuitry provide 0.1–100-$\mu$sec continuously variable control of pulse delay and duration.—Electro Pulse, Inc., 11861 Teale St., Culver City, Cal.

## Liquid Metal Pump

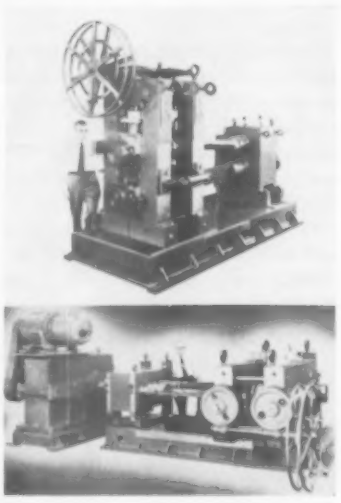
Hermetically sealed pump for high-temperature liquid metal can be supplied in capacities ranging from 150–5,000 gpm at operating temperatures up to 1,600° F.—Westinghouse Electric Corp., P. O. Box 2278, Pittsburgh 30, Pa.

## Air Filter

Filter medium consists of combination of selected glass and asbestos fibers. Minimum efficiency is 99.97% based on removal of 0.3-micron particles. Rated capacity of 24 × 24 × 11½-in. size is 1,100 cfm. Filters to withstand 1,000° F and 100% relative humidity are available. Filtering area is 200 sq ft.—Cambridge Filter Corp., 738 Erie Boulevard, East, Syracuse 3, New York.

## Scintillation Crystals

Thallium-activated sodium-iodide crystals, grown in ingots 5 in. in diameter and 4 in. long with 90-deg conical end (above), can be supplied in any sizes and configurations derivable from this shape. Cylinders, cylinders with truncated conical ends, and cylinders with re-entrant end wells can be supplied either unmounted, enclosed in standard mounts, or specially mounted to individual requirements. In addition, crystals are also available in high-resolution gamma-ray transducers consisting of 2-, 3-, and 5-in. crystals integrally mounted with appropriate photomultiplier tubes and enclosed in shielded housings having built-in preamplifiers.—Levintal Electronic Products, Inc., Stanford Industrial Park, Palo Alto, Calif.



## Convertible Rolling Mill

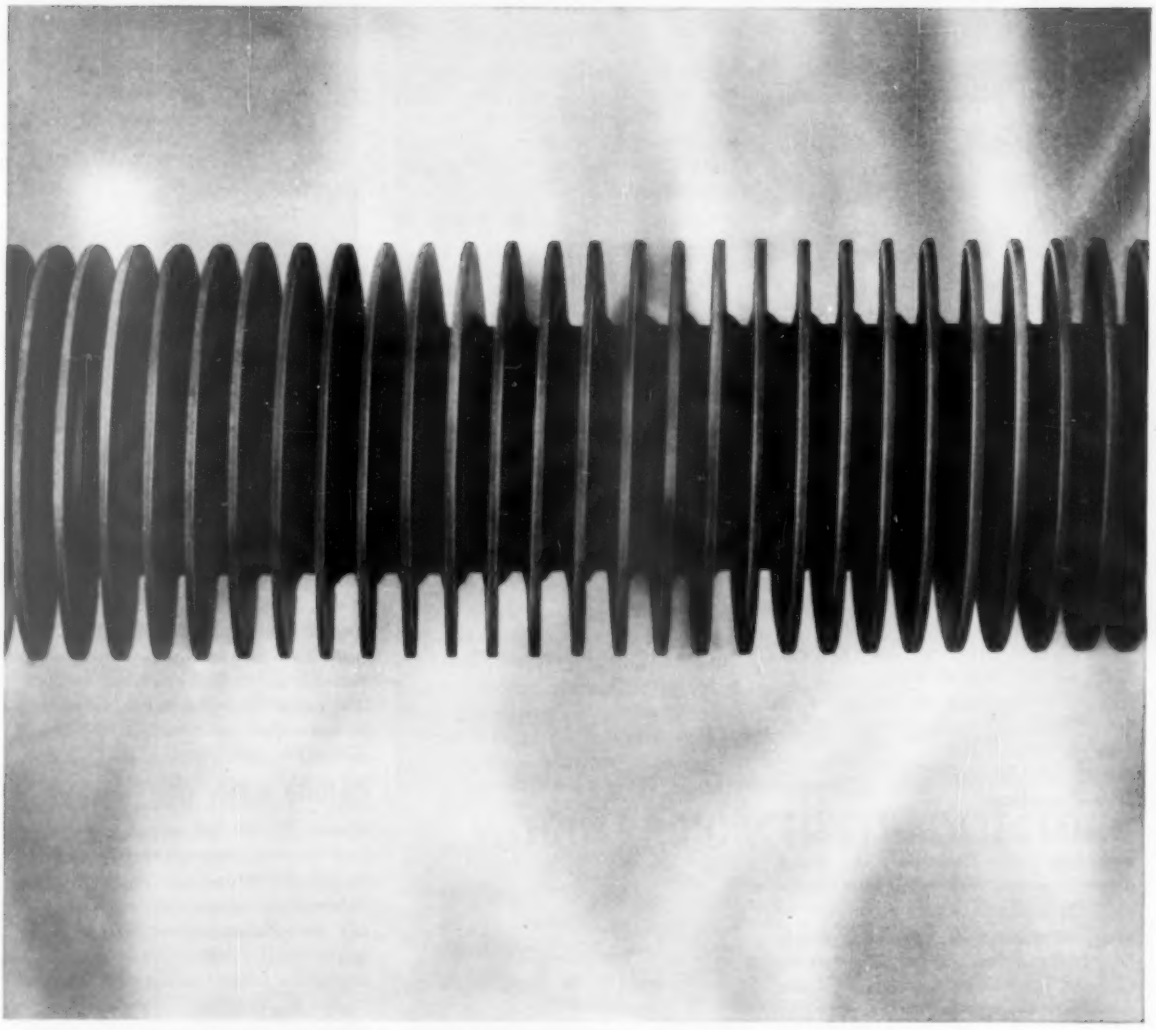
Model V4-126 (above) is two-high/four-high combination mill with 12-in. rolls and 40-hp variable-speed a-c drive. It can be used as vertical mill for rolling powdered metals or converted to standard horizontal mill for rolling strip by movement of pinion stand and roll housing.—The Fenn Manufacturing Co., Fenn Rd., Newington, Conn.

## Ratemeter

Model 412 dual ratemeter is log and linear multirange instrument with five-decade logarithmic scale that provides range of 10–1,000,000 cpm. Selectable by 10-position front panel switch, linear scale has ranges of 0–30 cpm, 0–100 cpm, etc., up to 0–1,000,000 cpm.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

## Radiation Barrier

Radiation barrier that can be taken down and reassembled consists of solid concrete blocks laid up with Weld-O-Bond No. 3111, a radiation-resistant adhesive used in place of conventional mortar. Special adhesive is resistant to radiation; it will not turn brittle nor deteriorate under prolonged exposure to radioactivity. It has good compressive and shear strength but no appreciable tensile strength; this is to permit barrier to be disassembled at any time, without damaging the blocks. To assure uniform application and to prevent "holidays" or gaps in vinyl-base bond, brilliant blue dye has been added.—California Stucco Products of New England, Inc., Cambridge, Mass.



*Deep-finned heat-exchanger tube developed for the British nuclear power stations.*

# The know-how on gas-cooled reactors

Only a year or two ago, a gas-cooled, graphite-moderated reactor was considered, by many people, an unpromising stop-gap as a power generator. It has, however, proved to be capable of such rapid development that in Britain the 1965 target for atomic power generation has been stepped up from 2,000,000 kW to 6,000,000 kW with very little increase in the number of stations.

Calder Hall, designed in 1953, develops 70,000 kW. By the time it became critical in 1956, 300,000 kW stations were coming off the drawing board. The latest station at Hinkley Point will have an electrical output of 500,000 kW.

This surprising advance is the result of knowledge gained during the structure and operation of Calder Hall: it is largely a matter of straightforward engineering development in which the companies of Tube Investments Limited have played an important part. Their know-how goes into components for the new stations but it is also available to assist all engineering firms engaged in atomic power production. And so are the components—such as this deep-finned heat-exchanger tube—designed and made by a T.I. Company.

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### Polyethylene Tanks

Industrial filtration tanks (above) fabricated from linear polyethylene have 27-in. o. d., ½-in. wall and are 36 in. deep. Tanks are fitted with linear polyethylene filtration piping of welded and threaded construction. Welded-steel support cradle with lug plates is used to position tank in process line.—American Agile Corp., P. O. Box 168, Bedford, Ohio

### Dye-Penetrant

Available in nonflammable or very-high-flash-point formulas in either pressure-spray cans or in bulk, Spotcheck is nontoxic, although should be used in reasonably ventilated areas, because made with chlorinated hydrocarbons, not carbon-tetrachloride-base solvents. Spotcheck penetrant and developer also available in water-wash formulas for removal by water spray.—Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill.

### Bellows-Seal Globe Valves

High-temperature bolted-bonnet valve for service up to 1,100° F and pressures up to 150 psig has safety stuffing box with radiating fins, type-321 stainless steel bellows and "O" rings and balance of parts of type-316 stainless. Available in sizes from ½–2 in.—Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.

### Aerosol Membrane Filters

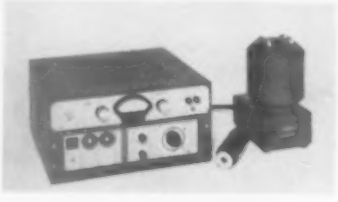
Type AM 5 units are made of cellulose esters and range in thickness from 50–120 microns. Dust collected on membranes can be brought into suspension by dissolving filters in acetone or other low-molecular-weight ketones, alcohols or esters. For direct microscopic examination of dust, membranes can be made transparent with immersion oil. Air permeability (at 50-cm water) is 100–150 liters/min/100 cm². Average pore size is 0.6–0.8 microns. Approximate size of dust retained is <0.3 micron.—Gelman Instrument Co., 233 Jefferson St., Chelsea, Mich.

### Cd Strip and Foil

Cadmium strip and foil is 99.95% pure, minimum. It is precision-rolled to widths from 4–6 in., in thicknesses from 0.300–0.0005 in. and to tolerances as close as ±0.0001 in.—American Silver Company, Inc., 36–07 Prince St., Flushing 54, N. Y.

### Zinc-Bromide Windows

Package units of standard sizes provide complete windows ready for installation. Instead of vinyl coating to protect window frame from attack by zinc bromide (causing window to cloud up), windows have copper lining that is unaffected by solution.—Research Equipment Co., 1032 College Ave., Wheaton, Ill.



### Scintillation Analyzer

System (above) is designed specifically for analytical measurement of isotopes emitting either gamma or hard beta rays or mixture of both in solid or liquid samples. Separation of gamma emitters by pulse-height selector to determine spectrum operating point allows integral spectrum analysis and determination of useful gamma pairs.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

### Nanosecond Timer

Timing device measures time intervals as short as billionth of second (or nanosecond in metric system of measurement). "Nanosec" consists essentially of time-to-amplifier converter and 20-channel amplitude analyzer.—Eldorado Electronics, 2821 Tenth St., Berkeley, Calif.

### Ultrasonic Thickness Gage

Model R Vidigage (above) is comprised of ultrasonic resonance-gaging and indicating circuitry, strip-chart recorder, gating and alarm circuits, and calibration control. Its power input at 60-cycle, 100–130 v a-c, is 500 w. For special requirements, 220-v, 50-cycle equipment is available. Thickness of metals, glass and plastics between 0.005 in. and 2.5 in. can be measured.—Bronson Instruments, Inc., 40 Brown House Rd., Stamford, Conn.

### Decade Scaler

Model T-1700 has count controls to provide instantaneous counting results on six-digit, in-line, neon readout. Fine and coarse controls for power supply provide adjustment from 500–3,000 v. Resettable, eight-digit register shows elapsed time in seconds and tenths of a second. Two input jacks provide 1 mv and 200 mv sensitivity. Over-all resolution time is <1μsec with maximum counting rate of >500,000 pps. Linear, feedback-type amplifier has gain of more than 1,000. High voltage is stabilized to 0.01%. Load regulation is 0.05% for a 10% current increase at any load up to maximum.—NRD Instrument Co. Div., Nuclear Corporation of America, 9842 Manchester Rd., St. Louis 19, Mo.

### Stainless-Steel Valves

Renewable disc "Y" valves are provided with extra lift to remove disc from flow area and minimize line entrapment and pressure drop. Valves are designed to ASA B 16.5 and MSS SP-42 specifications. Produced in ¼–3-in. sizes for screw and socket weld connection and ½–8-in. sizes for flange connection, valves operate in pressure range from vacuum to 275 psi at temperatures to 750° F. Standard disk material is Teflon, although other

materials are available on request.—Cooper Alloy Corp., Hillside, N. J.

### Titanium Pipe Fittings

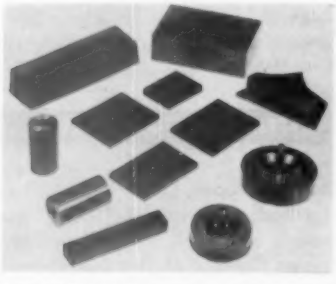
Complete line of welding fittings and flanges of commercially pure titanium to match any schedule and size of titanium piping are offered.—Tube Turns Div., National Cylinder Gas Co., Louisville, Ky.

### Linear Ratemeter

Model RM-7 converts randomly spaced pulses from external sensing source into average counting rate per minute presented on panel meter in one of seven linear ranges or in logarithmic scale. Logarithmic-scale circuit permits initial counts to be made over range of 30–300,000 cpm prior to selection of optimum linear scale.—Technical Associates, 140 W. Providencia Ave., Burbank, Cal.

### Ion Chambers

High-temperature (up to 300° F) design plus shock and vibration resistance are features of line of ion chambers developed specifically for nuclear reactor applications. Included are compensated and uncompensated neutron-sensitive chambers, gamma sensitive chambers, fission counters and proportional counters. All are capable of covering neutron flux changes from $10^{-1}$–$10^{11}$ nv. Compensated chambers have fixed geometrical compensation exceeding 95%.—General Electric Co., Schenectady 5, N. Y.



### Plastic Shielding

Leadcast is epoxy-based, lead-filled, thermosetting casting compound that produces homogeneous castings (above) with an as-cast tolerance of 0.0005. It has density of 6.6 gm/cm³, finished, glossy appearance and hardness can be controlled from that of a semirubber-like material to that equivalent to cast aluminum. Leadcast also can be fabricated in standard construction sizes from wall tile to 4 × 8-ft panels.—Telectro Industries Corp., 35–16 37th St., Long Island 1, N. Y.

# N. WOOD RADIOACTIVITY DETECTORS

Shown here are a variety of neutron and cosmic ray counters featuring a 36" long counter ½" in dia. and our micro-neutron counter with 3/16" x ¼" active volume. Other counters range in size from ½" dia. x 2½" active length to 2" dia. x 38" active length and are filled at various pressures from 12 cm. to 120 cm. They are made of brass or aluminum and are fitted with 82–805 teflon connectors. They are used with standard commercial type scalers with one millivolt input sensitivity.

The display includes the 1½" x 34" active G-15-34A neutron counter now used in cosmic ray installations and in I G Y research all over the world.

Also shown is the new 2" x 40" cosmic ray proportional counter, which like the neutron counter has almost unlimited life.

We have a complete line of glass-wall counters including thin wall jacketed counters and bismuth cathode counters.

Our Scintillation counters include the SC-1U Universal counter shown below which takes interchangeable alpha, beta, fast and slow neutron crystals as well as gamma crystals of various sizes including the well-type.

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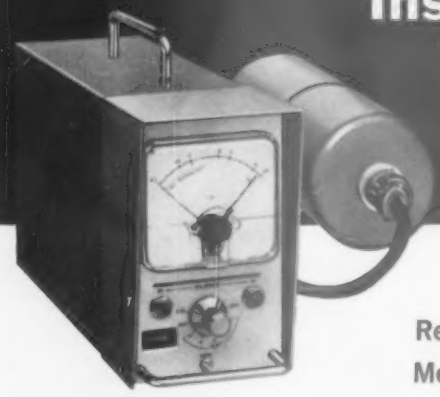
# RIGGS Nuclear/Industrial Area-Monitoring Instruments



## RIGGS
### Remote Area Gamma Monitor (GA-3 Series)

A completely self-contained, independent system with pressurized logarithmic response ionization chamber. Model GA-3B has Mercury battery supply for 4 months continuous operation. Model GA-3BA same as GA-3B but with AC power supply failsafe to DC. Model GA-3A available in AC power supply only.

### RELAY RACK MOUNTING

The RIGGS four-gang rack unit may be any combination of the above GA-3 series remote area monitoring instruments. A separate power supply is not required. This eliminates the possibility of complete shutdown in event of power supply failure or during maintenance to the monitoring instruments.
The RIGGS system permits service to each individual unit, when necessary, without affecting continuous monitoring by the others.

**General Features and Specifications**

Any continuous combination 3-decade logarithmic ranges from .01 mr/hr to 100,000 R/hr.

**Energy Dependence**
Flat to within ±10% from 80 Kev. to 1.2 Mev.

**Alarm Control System**
Meter relays DC, manual reset.
Alarm relay rated 115V AC 2 amps.

**Recorder Output**
10 mv operated directly from output of unit.

**Electronic Calibration**
Complete circuit check of all ranges both ends of scale.

**Multiple Channel Area Monitoring System (AMS-II)**

This system features a console-type cabinet (19"x21"x12"), with provisions for ten radiation channels, a transistor power supply, electronic calibration, an alarm system, optional fail-safe power supply, ionization chamber hermetically sealed permit wide temperature and moisture variations, completely submergible, requires no external voltage regulation device. The same radiation specifications apply to this system as our GA-3 instruments.

### Logarithmic Gamma-Beta Portable Survey Meter (GB-4)

Logarithmic response, pressurized ionization chamber. Portable survey meter has two, 3-decade ranges. Model GB-4 provides ranges .01 to 10 mr/hr—.01 to 10 R/hr. — fast monitoring of high and low level Gamma-Beta radiation. Energy dependence: flat to within ±10% from 80 Kev. to 2 Mev. Other ranges available.

Write for free illustrated technical literature and price lists.

Patents Pending.

RIGGS NUCLEONICS CORP.
717 North Victory Boulevard, Burbank, California

### Recording Spectrometer

Model 5-11 (above) scans continuously between base-line settings of 0 and 100 v with complete scan represented by 20 in. of paper travel. Paper speed can be 7.5–240 in./hr (scanning time 2½ hrs–5 min). Display size remains unchanged with changes in scanning speed. In conjunction with recorder is combination nonoverloading linear amplifier and single-channel pulse-height analyzer with precision window amplifier. Ratemeter features six full-scale ranges from 300–100,000 cpm and permits selection of probable error range of 1%, 3% or 10%.—Technical Measurement Corp., 140 State St., New Haven, Conn.

## LITERATURE AVAILABLE

**Stable isotopes,** $C^{13}$, $O^{18}$ and $N^{15}$, and standard and special labeled compounds are listed in Bulletin 256.—Isomet Corp., P. O. Box 341, Palisades Park, N. J.

**"Pioneering New Horizons in Power"** is title of 36-p. brochure.—Pioneer Service & Engineering Co., 231 S. La Salle St., Chicago 4, Ill.

**Lead isotope containers** are described in 2-p. Bulletin 190.—American Smelting & Refining Co., 120 Broadway, New York 5, N. Y.

**"Breeder's Digest"** is title of news letter aimed at keeping all concerned informed on developments involving

Enrico Fermi fast breeder reactor.—Power Reactor Development Co., 1911 First St., Detroit 26, Mich.

**"Multichannel Analysis"** is title of 15-min color film describing various means of detecting and measuring radioactivity.—Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

**Epoxy-based masonry materials** are described in 12-p. brochure.—CIBA Co., Kimberton, Pa.

**Electrometer** and other instruments are described in 4-p. catalog.—Gyra Electronics Corp., 518 N. Spring Ave., La Grange Park, Ill.

**Electronic recorder** information is presented in Publications 57-1190-47 and 58-1223-41.—The Hays Corp., Michigan City, Ind.

**Fuel-element fabrication** facilities are described in 5-p. bulletin.—D. E. Makepeace Co., Pine and Dunham Sts., Attleboro, Mass.

**"A Decade of Pioneering"** is theme of 24-p. brochure that gives special attention to firm's work on hydrogen thyratrons and μsec oscilloscopes.—Edgerton, Germeshausen & Grier, Inc., 160 Brookline Ave., Boston 15, Mass.

**Thermometers,** indicating, recording and controlling, are described in 56-p. Catalog C60-2.—Minneapolis-Honeywell Regulator Co., Wayne & Windrim Aves., Philadelphia 44, Pa.

**Quality control** services are described in 4-p. bulletin.—Burns and Roe, Inc., 160 W. Broadway, New York 13, N. Y.

**Dall flow tubes** are subject of 20-p. Bulletin 115-L3C that gives comprehensive technical data on design, metering characteristics, flow formulae, etc.—Builders-Providence, Inc., 345 Harris Ave., Providence 1, R. I.

**$C^{14}$-labeled compounds** are given price list.—Nuclear-Chicago Corp., 233 W. Erie St., Chicago 10, Ill.

**Radiation protection** and film processing and isotope and inspection equipment are described in 56-p. catalog.—Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y.

**Precision balls,** their electric, magnetic and corrosion-resistance properties, are shown on two charts.—Hartford Steel Ball Co., Inc., West Hartford 6, Conn.

**Digital computer** theory, design, philosophy, programming and use is introduced in 8-p. Reprint S-475; Model LGP-30 is described in 12-p. Bulletin S-526.—Royal McBee Corp., Westchester Ave., Port Chester, N. Y.

**Instrument repair** service details are given in 2-p. Folder EN(6).—Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.

**Remote-control microscope** for metallurgical investigation of radioactive materials is described in 5-p. bulletin.—William J. Hacher & Co., Inc., 82 Beaver St., New York 5, N. Y.

**Chromatography equipment** and accessory apparatus is given Price List 1356B.—Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.

**Film-badge** service is outlined in 2-p. pamphlet.—St. John X-Ray Laboratory, Califon, N. J.

**Radiation-resistant cable** is listed in 12-p. brochure.—Boston Insulated Wire & Cable Co., 65 Bay St., Boston 25, Mass.

**"Research in Chemical Processing"** is title of 16-p. brochure.—Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

**Mechanical remote controls** is subject of 28-p. catalog.—Teleflex Inc., North Wales, Pa.

**Rolling mills** are subject of catalog.—Fenn Manufacturing Co., Newington, Conn.

**Liquid scintillation** spectrometers for counting tritium and carbon-14 samples are described in 4-p. Specification No. 314.—Packard Instrument Co., Inc., P. O. Box 428, La Grange, Ill.

**Small valves** are covered in 12-p. Catalog MV-957.—Hoke, Inc., 136 S. Dean St., Englewood, N. J.

**Glove boxes** are described in 6-p. Bulletin A-11.—S. Blickman, Inc., 8400 Gregory Ave., Weehawken, N. J.

**Ion chambers** are described in 4-p. Bulletin GEA-6631.—General Electric Co., Schenectady 5, N. Y.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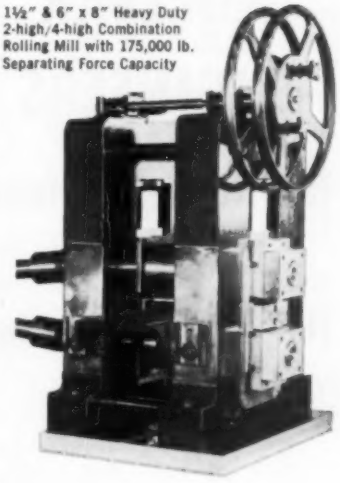

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# INDUSTRY NOTES

**Industry Notes, heretofore a section within our Products and Materials department, has been promoted to department status as of this issue. The aim, of course, is to give more space and attention to the business side of nucleonics, including new firms, financial news, expansions, company moves, contract awards and the other facets of commercial activity. All companies have a standing invitation to submit material of this nature for publication.**

● **Volk Radiochemical,** Chicago, has created a radiomedical department under Leonard Walker, formerly of Nuclear Consultants, St. Louis. When the new department is fully staffed and equipped, Volk will be able to supply all proven radiopharmaceuticals.

● Thompson Products and its Los Angeles affiliate, Ramo-Wooldridge, have merged, creating the **Thompson Ramo Wooldridge Corp.** Simultaneously, Thompson has moved ahead with its reorganization program: 1. creating a sales-marketing organization in its Tapco group to serve the nuclear and other fields; and 2. forming a new-products group to support the sales organization.

● **Research Specialties,** Berkeley, has begun construction of a $275,000 manufacturing plant at Richmond, Calif. It will produce carbon-14 and other radiochemicals, as well as instruments.

● **Nuclear-Chicago** has improved its "nuclibadge" service to provide individual exposure reports for customer employees. In another innovation, the reports will be exact duplicates, rather than copies, of those in N-C's files.

● **WaiMet Alloys,** Detroit, has entered into an exclusive sales agreement with **Allvac Metals,** Monroe, N. C., for the sale of vacuum-melted alloys.

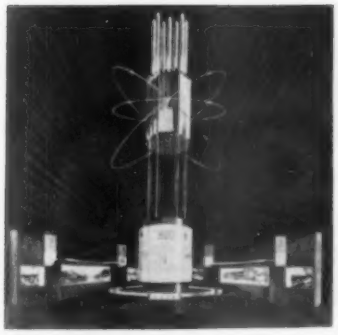
**NEW FIRMS.** In New York City, **Manhattan Physical Research Group** —formed by eight research scientists to offer "extra-high-level research" services to nuclear and other firms. President is Cyrus Adler, professor of physics and electronics at City College of New York. . . . **Compagnie Francaise d'Etudes et de Construction** (TECHNIP), Rueil-Malmaison, France—formed by Catalytic Construction, the French Atomic Energy Commission, Institut Francais du Pétrole and Société Nationale des Pétroles d'Acquitaine; will provide complete plants in Europe —from engineering through design—for the nuclear, petroleum, chemical and petrochemical industries. . . . **Jaeco Pump Co.,** Villanova, Pa.—formed to manufacture proportioning and power pumps for nuclear power and other applications. . . . In Italy, only seven months after setting up Vitro International, Vitro Corp. of America founded Vitro Italiana S.p.A. with headquarters in Rome and $1-million capital.

**FINANCIAL.** A slight increase in sales—from $294,590,000 to $294,894,000—was reported by **ACF Industries** for the year ending April 30. Sales declines in its valve and railcar divisions were partially offset by reactor sales of its Nuclear Products-Erco div. and increased work by the division at the Albuquerque plant operated for AEC. . . . The common stock of **Victoreen Instrument Co.** has been admitted to the American Stock Exchange; ticker symbol is VIC.

**NEW BUSINESS.** Four canned-motor primary coolant pumps for N.S. *Savannah* have been ordered from **Allis-Chalmers,** two per loop. They will have a design rating of 5,000 gpm at 70-psi head; operating pressure of the primary coolant will be 1,750 psi at all loads, temperature, ~500° F. . . . **A-C** will also supply a 16,000-sq-ft, two-pass condenser and a tray-type deaerator for AEC's experimental breeder reactor (EBR-2). . . . **Leeds & Northrup** has a $250,000 contract for a complete control center for the test reactor to be built at Sandusky, Ohio, by the National Advisory Committee for Aeronautics.

**COMPANY MOVES.** From Milford, Conn., to temporary quarters in Raleigh, N. C.—**Astra Inc.;** eventually Astra will move to Research Park in the "research triangle" between Raleigh, Chapel Hill and Durham. . . . **Radiochemistry, Inc.**—from Tulsa to Louisville (1101 W. Saint Catherine St.). . . . **G. C. Dewey & Co.**—to larger quarters at 202 E. 44th St., New York 17.

## GENEVA PREVIEW



# U. S. Exhibitors at Geneva—1958

Half a hundred U. S. companies plus the U. S. Atomic Energy Commission will participate with companies from 13 other nations in the commercial exhibition to be held in conjunction with the second Geneva Conference next month. The U. S. portion of the exhibition will occupy approximately 32,000 sq ft in the recently enlarged *Palais des Expositions* in downtown Geneva. Across town, in a temporary building on the grounds of the *Palais des Nations*, will be the government exhibits. The U. S. exhibit there will include the TRIGA reactor and the human counter (see pp. 106 and 116).

The following listing contains all U. S. Commercial exhibit descriptions available as NUCLEONICS went to press, as supplied by the exhibit coordinator. The numbers in parentheses are *Palais des Expositions* booths in U. S. section.

**ACF Industries, Inc., 508 Kennedy St., N. W., Washington 11, D. C.** Displays of research reactors under construction and gas-cooled and boiling-water power reactors being designed; model of power reactor for Elk River, Minn. with dummy fuel element and operating control-rod drive. (19)

**Aerojet-General Nucleonics Div., Aerojet-General Corp., San Ramon, Calif.** Operating training reactor. (28)

**ALCO Products, Inc., Schenectady 5, N. Y.** Displays of power reactors, including newly designed, skid-mounted plant; operating control-rod drive; sine-wave tubes. (46)

**Allis-Chalmers Manufacturing Co., 935 S. 70th St., Milwaukee 1, Wis.** Displays of reactors, uranium-mining equipment. (10)

**American Lava Corp., Manufacturers Rd., Chattanooga 5, Tenn.** (27B)

**American Machine & Foundry Co., 261 Madison Ave., New York 16, N. Y.** Displays of power and propulsion reactors, remote-handling equipment, fuel-element fabrication plant; research-reactor simulator operating control-rod drives over mocked-up core. (47)

**American Nuclear Society, Inc., 86 E. Randolph St., Chicago 1, Ill.** (27C)

**American Radiator & Standard Sanitary Corp., 369 Whisman Rd., Mountain View, Calif.** (31)

**Atomic Industrial Forum, Inc., 3 E. 54th St., New York 22, N. Y.** Display outlining activities; motion-picture theater (seats 125) showing 15 industrial and 13 government films in continuous performance. (34, 34A)

**Atomics International Div., North American Aviation, Inc., P. O. Box 309, Canoga Park, Calif.** Models of Piqua, Ohio and Hallam, Neb. power reactors and conceptual designs for organic-moderated power and propulsion reactors; working model of reactor core and coolant loop. (49)

**The Babcock & Wilcox Co., 161 E. 42nd St., New York 17, N. Y.** Displays featuring facilities for design, fabrication and testing of reactors and components. (52)

**Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.** Automatic sample-changer system; automatic recording spectrometer; fast glow-tube scalers; displays of direct-reading spectrometer and 3-m grating spectrograph. (40)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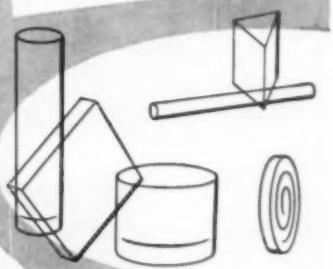

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- THIN FILAMENTS OF NE102 for image intensification, or solid scintillation detectors.
- FAST NEUTRON DETECTOR NE404
  This is a *new product* and consists of concentric cylindrical annuli of hydrogenous ZnS (Ag) dispersion separated by annular light guides.
- SLOW NEUTRON DETECTOR NE400
  This boron polyester composition is now mounted in a more efficient geometry incorporating concentric cylindrical grooves for improved light collection.
- PLASTIC PHOSPHOR NE102
  This efficient and proven plastic scintillator is available as slabs, sheets, cylinders and an endless variety of special geometries. Unmachined ingots can be furnished in pound or ton quantities.
- LOADED LIQUID SCINTILLATORS
  Efficient detectors loaded with Gd, Cd, Pb or newly available Sm. Also scintillating gels and scintillation chemicals.

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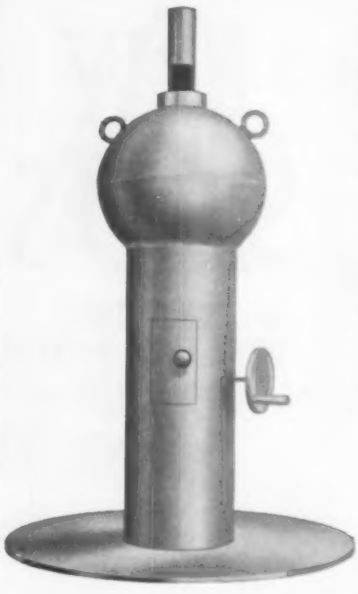

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## GENEVA PREVIEW

*Article starts on page 155*

**Ball Brothers Research Corp., P. O. Box 191, Boulder, Colo.** Scintillation counters, gamma logging equipment, fluorimeter. (17)

**The Beryllium Corp., P. O. Box 1462, Reading, Pa.** Beryllium metal shapes, powder, bead and billet; BeO shapes and powder. (22)

**The Brush Beryllium Co., 4301 Perkins Ave., Cleveland 3, Ohio.** QMV Beryllium shapes and BeO. (8)

**The Carborundum Metals Co., P. O. Box 32, Akron, N. Y.** Zirconium sheet, tubing, strip, foil, wire and shapes. (26)

**Columbia-National Corp., 70 Memorial Dr., Cambridge 42, Mass.** Zirconium sponge, mill products and fabricated shapes; tantalum powder, foil and mill products; display of high-vacuum furnaces and equipment. (2)

**Combustion Engineering, Inc., 200 Madison Ave., New York 16, N. Y.** Displays of nuclear facilities at Windsor, Conn. and Chattanooga, Tenn. (39)

**Consolidated Edison Co. of New York, Inc., 4 Irving Pl., New York 3, N. Y.** Displays of work in progress at Indian Point, N. Y., nuclear power plant site. (23)

**Curtiss-Wright Corp., 304 Valley Blvd., Woodridge, N. J.** Control-rod drive systems, reactor-core grid plate and suspension system, reactor console, fuel elements, BeO reflector elements, control rod, scintillation probe, $BF_3$ detectors, subcritical reactor and associated equipment, beta gage, air sampler, displays of research and propulsion reactors. (30)

**Edgerton, Germeshausen & Grier, Inc., 160 Brookline Ave., Boston 15, Mass.** Traveling-wave oscilloscope and associated equipment, hydrogen thyratron, cathode-ray tube, stroboscopic systems, xenon flashtubes, display describing planning and operation of large-scale field testing and research programs. (15)

**Edison Electric Institute, 750 Third Ave., New York, N. Y.** Display showing role of U. S. electric-power companies in reactor research, development and construction. (25)

**The Edlow Lead Co., 729 Bank St., Columbus 16, Ohio.** Radioactive-waste disposal containers, lead bricks and fabricated shapes, fuel-element shipping cask. (44)

**General Atomic Div., General Dynamic Corp., P. O. Box 608, San Diego 12, Calif.** Full-scale model of TRIGA core (see p. 116) with ten encapsulated, 10-μc $Co^{60}$ sources in specimen rack; model of after portion of merchant ship showing proposed gas-cooled reactor; model of central-station power plant showing gas-

cooled reactor; operating thermonuclear apparatus. (7)

**General Electric Co., 2151 S. First St., San Jose, Calif.** Display of products and facilities; small motion-picture theater; models of Dresden, Ill. nuclear power station, General Electric Test Reactor, pool-type research reactor and boiling-water and other type propulsion reactors; dummy fuel elements; control-rod drives; micromicroammeter. (48)

**General Mills, Inc., 1620 Central Ave., Minneapolis 13, Minn.** Hot-cell model with model manipulator and GMI Mechanical Arm forearm. (12)

**Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. J.** Scintillation spectrometer, logarithmic counting-rate, meter, mercury-switch pulser, pulse-height analyzer, pulse generator. (24)

**High Voltage Engineering Corp., S. Bedford St., Burlington, Mass.** 6-Mv Van de Graff accelerator, model of 10-Mev tandem Van de Graff, display on research activities with Van de Graff and microwave linear accelerators. (6)

**Internuclear Co., 7 N. Brentwood Blvd., Clayton 5, Mo.** (37)

**P. M. Lennard Co., Inc., 1 Hanson Pl., Brooklyn 17, N. Y.** Glove and dry boxes of plastic and stainless steel. (43)

**Lindsay Chemical Div., American Potash & Chemical Corp., 258 Ann St., West Chicago, Ill.** Cesium, rubidium, lithium, boron, thorium and rare earths. (16)

**Lockheed Aircraft Corp., Marietta Ga.** Display of peaceful uses of atomic energy. (18)

**M & C Nuclear, Inc., 34 Forest St., Attleboro, Mass.** Models of various fuel elements including concentric-tube type, plate type and pellet-filled-tube type. (14)

**Mallinckrodt Chemical Works, 2nd & Mallinckrodt Sts., St. Louis 7, Mo.** Display featuring fuel fabrication facility at Hematite, Mo. and samples of uranium compounds of natural enrichment. (20)

**Mallory-Sharon Metals Corp., 980 Warren Ave., Niles, Ohio.** Zirconium and titanium mill products and fabricated shapes; displays highlighting properties of zirconium and hafnium, study of zirconium vs stainless steel economics and Zr-Hf separation process. (13)

**The Martin Co., Baltimore 3, Md.** Natural uranium fuel elements. (4)

**Minneapolis-Honeywell Regulator Co., Wayne & Windrim Aves., Philadelphia 44, Pa.** Reactor simulator. (41)

**Molesworth Associates, Inc., 260 Madison Ave., New York 16, N. Y.** (21)


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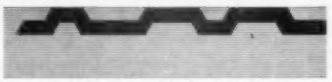

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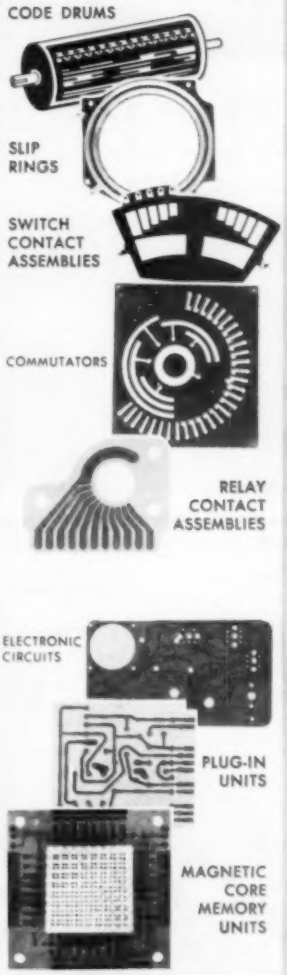


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## GENEVA PREVIEW

*Article starts on page 155*

**Nuclear Development Corp. of America, 5 New St., White Plains, N. Y.** Display showing activities and facilities, including reactor models. (11)

**NUCLEONICS, McGraw-Hill Publishing Co., 330 W. 42nd St., New York 36, N. Y.** Display including bound volumes of NUCLEONICS 1947–1957 and selected reprints; headquarters for meeting editorial, sales and circulation staff members. (38)

**Packard Instrument Co., Inc., P. O. Box 428, La Grange, Ill.** Automatic liquid scintillation spectrometer, automatic sample changer and windowless flow counter. (32)

**Picker X-Ray Corp., 25 S. Broadway, White Plains, N. Y.** Cobalt irradiators, therapy stretcher, scaler, scintillation detector probe. (45)

**Power Reactor Development Co., 1911 First St., Detroit 26, Mich.** Display including slides covering progress on Enrico Fermi Fast Breeder and model. (36)

**Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.** 256-channel pulse height analyzer; 128-channel scaler-analyzer; neutron survey meter; scintillation, proportional and G-M counters; decade scaler. (9)

**Specialty Engineering & Electronics Co., 79 Clifton Pl., Brooklyn 38, N. Y.** Automatic gas alarm, dosimeters, survey meter. (33)

**Sylvania-Corning Nuclear Corp., Bayside, N. J.** Display of fuel elements, including plate (aluminum and stainless steel), pellet, pin and slug types. (5)

**Tobe Deutschmann Corp., Providence Hwy., Norwood, Mass.** Small thermonuclear pinch-tube demonstration, fast discharge capacitors with energy storage banks. (42)

**Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.** Manual sample changer, chromatogram scanner, carbon-14 counter, scalers, ratemeter, recorder, scintillation counter and other nuclear instruments. (50)

**Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.** Nuclear graphite in various grades and machined shapes, fine metal in roundals and ingots and rare gases. (53, 53A)

**U. S. Atomic Energy Commission, Washington 25, D. C.** Mobile radioisotope laboratory, training reactor exhibit, information center, publications exhibit, robot manipulator. (27, 29, 29A, 35, 54)

**Vitro Corp. of America, 261 Madison Ave., New York 16, N. Y.** Display depicting activities. (3)

**Westinghouse Electric Corp., 3 Gateway Ctr., Pittsburgh 30, Pa.** (1)

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# NEWSMAKERS

**Harvard L. Hull,** a nucleonics pioneer, has left the presidency of Cook Electric's Nucledyne subsidiary to form his own consultant business—Hull Associates, 30 W. Monroe St., Chicago.

AEC has named **Harry H. Gorman** to head its new Lockland, Ohio, Aircraft Reactors Operations Office. New staffers in AEC's New York Operations Office: **Wesley M. Johnson,** assistant manager for technical operations, and **Joseph L. Smith,** assistant manager for administration.

**Marcel A. Cordovi** has joined the atomic power developments section of the development and research div., International Nickel Co. He formerly headed the materials and testing dept. of the atomic energy div., Babcock and Wilcox. A nuclear materials specialist, Cordovi has served with special committees of the Atomic Industrial Forum, American Society for Testing Materials and American Society of Mechanical Engineers.

Cordovi

In a top-level reorganization of its Cincinnati div., Bendix Aviation has appointed **L. E. Rasmussen** to the new post of general manager and **Henry B. Yarbrough** to the new post of general sales manager.

**Jess Larson,** Washington attorney and authority on strategic materials, has been elected president of the Uranium Institute of America, succeeding **Patrick Hurley.** Larson is a former head of the General Services Administration and the Defense Materials Procurement Administration; he is a director of Jen, Inc., operator of uranium properties near Moab, Utah.

Larson

Radiation Applications has appointed **Jacques J. Weinstock** senior scientist. He joined the firm from Columbia Univ.'s mineral beneficiation laboratory, where he led the successful work on a continuous process for the extraction of uranium from low grade ores.

**David G. Fulton,** former program manager for ACF Industries, has been appointed comptroller of the Nuclear Products-Erco div.

Landsverk Electrometer Co. has named **Charles D. Gould** chief project engineer. Gould was the founder and a director of L. G. Research and for the past fourteen years has been project and chief engineer at Victoreen Instrument Co. A highlight of this period was his work as director of the radioactive telemetering program at the first Pacific nuclear bomb tests.

Gould

Radiation, Inc., has promoted **Lloyd R. Everingham,** a technical advisor for the past year, to vice-president in charge of research—a new post. The move gives new emphasis to the firm's expanded research program.

Another radiation firm, Radiation Counter Laboratories, has promoted two of its personnel: **George Kalantis,** from field engineer to sales engineer; and **Matthias Deppong,** from test engineer to field engineer.

Two chemists and two physicists have joined the atomic energy div., Phillips Petroleum Co. They are: **John J. Bordeaux,** corrosion group leader at the Idaho chemical plant; **S. Frederick Marsh,** radiochemical analyst at the same plant; and **Zoel R. Martinson** and **Edward Yeates,** reactor physics and engineering branch.

**Frank S. Briggs,** a 16-year employee of Tube Turns, has been appointed manager of the company's new nuclear energy and power plant section, sales development department. Tube Turns is a division of Chemetron Corp. Since joining the sales department in 1955, Briggs has specialized in the application of welded fittings

Briggs


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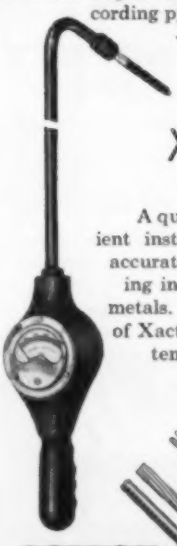

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New members of the staff of General Atomic div., General Dynamics, include: **Albert P. Graff,** manager of the training, research and isotope program; **G. W. Stuart,** research physicist; and **Claude C. Cardwell,** head of the field services group.

**Corneille O. Strother** has won appointment to the vice-presidency for research, Union Carbide Nuclear Co., capping almost 25 years with various branches of the parent firm—Union Carbide Co. Strother joined UCC in 1935 as a research chemist for Union Carbide Chemicals, later went to Linde Co., then to UCC headquarters in New York as assistant manager for physical chemistry, research administration.

Strother

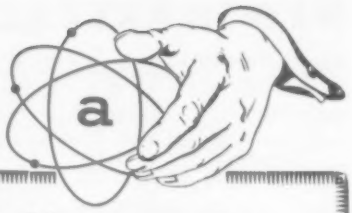
National Lead Co. has selected **A. Stewart, Jr.,** to direct production of nuclear fuel elements at its new Albany, N. Y., plant. Former assistant plant manager at National Lead's Fernald, Ohio, feed materials plant, Stewart's new title is manager, industrial dept., nuclear metals div.

**Harry E. Kenton** has been named director of personnel at Argonne National Laboratory.

Realigning the management of its research center, Clevite Corp. has promoted **A. L. W. Williams** from director of the center to vice-president of the firm. His job will be filled by two men: **Hans Jaffe** as director of electronics research and **Arthur D. Schwope** as director of mechanical research. Schwope had been in charge of the center's nuclear materials program.

Williams

**Ronald J. Grenda** has been named assistant engineer in the mechanical design group, nuclear power div., Allis-Chalmers.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## NUCLEAR CALENDAR

**Sept. 1-13**—Second International Conference on Peaceful Uses of Atomic Energy, Geneva, sponsored by United Nations. Contact Sigvard Eklund, United Nations, N. Y.

**Sept. 7-11**—World Power Conference, Montreal (*The Queen Elizabeth*). Proceedings, in English and French, include trends in nuclear power; post-conference tour of Shippngport avaiilable. Contact T. M. Patterson, c/o Editorial Associates, Suite 220, 1255 University St., Montreal.

**Sept. 15-19**—5th Ottawa Symposium on Applied Spectroscopy, Canada. Contact D. R. Jackson, 1801 Le Ber St., Montreal, P. Q., Canada.

**Sept. 15-19**—International Instrument-Automation Conference, Philadelphia (*Convention Hall*), sponsored by the Instrument Society of America. Program includes two technical sessions on nuclear instruments. Contact Fred J. Tabery, 3443 S. Hill St., Los Angeles.

**Sept. 16-20**—International Symposium on Nuclear Electronics, Paris (*UNESCO House*). Contact Colloque International Electronique Nucleaire, 10 Avenue Pierre-Larousse, Malakoff (Seine), France.

**Nov. 6-7**—Sixth annual meeting, Professional Group on Nuclear Science, Institute of Radio Engineers, San Mateo, Calif. (*Villa Hotel*). Four sessions. Contact H. Malcolm Ogle, General Electric, San Jose, Calif.

**Nov. 9-12**—Annual meeting, Atomic Industrial Forum, Washington, D. C. (*Shoreham*). Contact E. Wiggin, 3 East 54th St., New York 22.

**Dec. 1-5**—23rd National Exposition of Power and Mechanical Engineering, New York (*Coliseum*). Sponsored by American Society of Mechanical Engineers. Concurrent technical sessions of Nuclear Engineering div., ASME. Contact International Exposition Co., 480 Lexington Ave., New York 17.

**Dec. 8-10**—Winter meeting, American Nuclear Society, Detroit. Contact Octave DuTemple, 86 E. Randolph St., Chicago.

**Jan. 28-29**—First International Symposium on Nuclear Fuel Elements, Columbia Univ., New York. Sponsored jointly by Columbia and Sylvania-Corning Nuclear Corp. Contact H. H. Hausner, 730 Fifth Ave., New York 19.

**April 5-10**—Fifth Nuclear Congress, Cleveland (*Public Auditorium*). Outlines of technical papers due by Oct. 1. Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.


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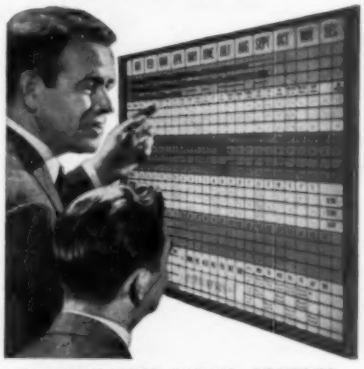

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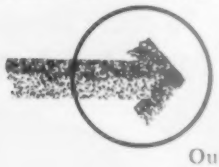

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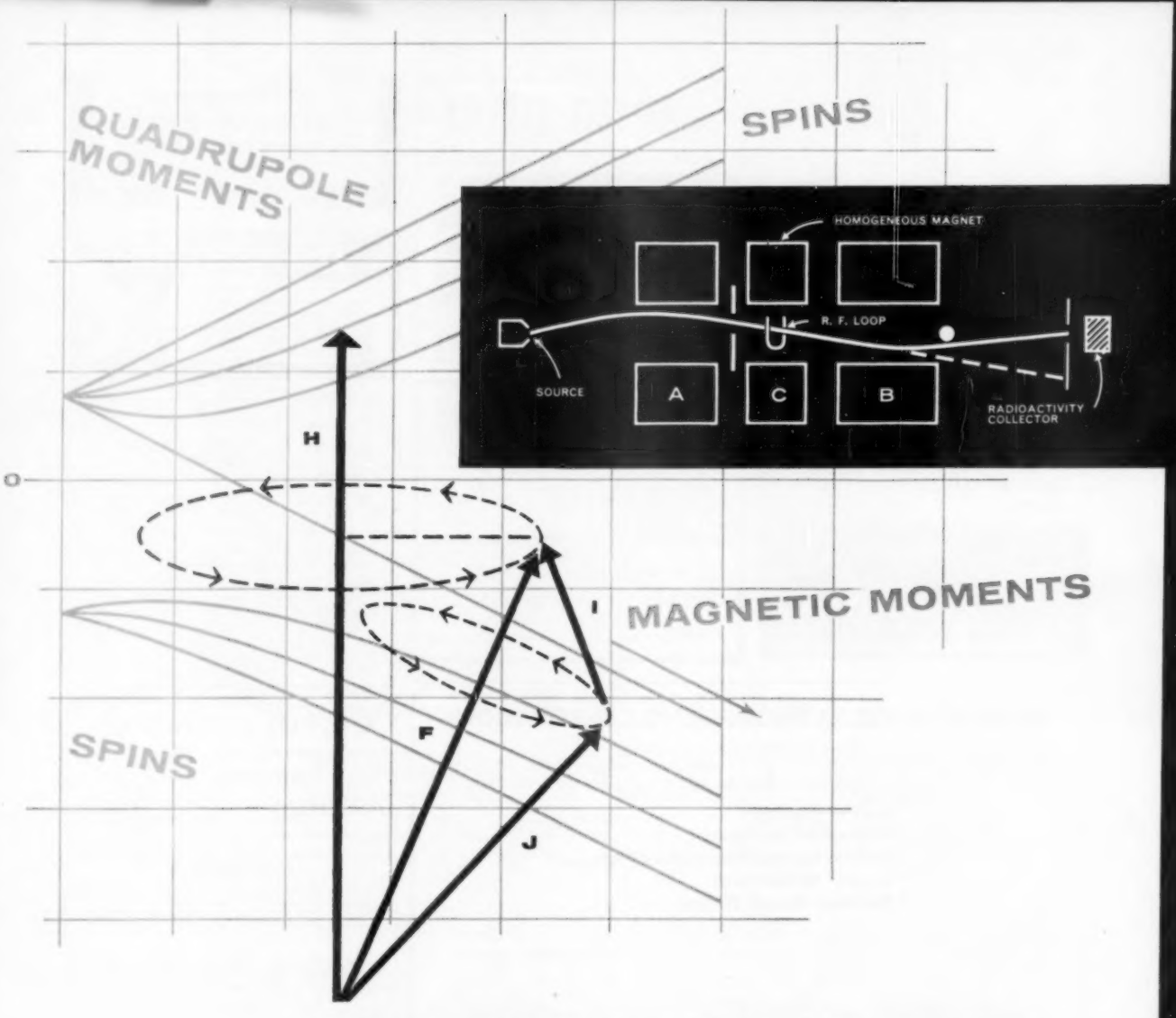


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KAPL Metallurgist Richard L. Mehan taking a reading on a Zirconium alloy specimen being tested in a special strain-fatigue apparatus. Conceived, developed and built at KAPL, this new apparatus makes it possible to control and measure elastic and plastic strain developed in reactor materials under test. Conventional equipment controls only stress and strain within the elastic region.

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Richard L. Mehan is one of several metallurgists working on the development of new and more reliable reactor materials at KAPL. Dick Mehan joined General Electric after graduation from MIT in 1950 and came to KAPL in 1953, following two years of army service. He is also studying advanced metallurgy, evenings at Rensselaer Polytechnic Institute under G.E.'s advanced degree program.

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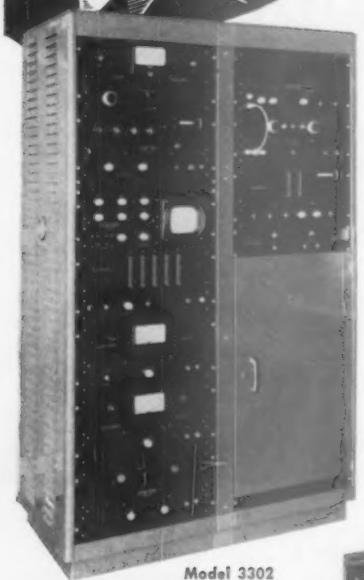

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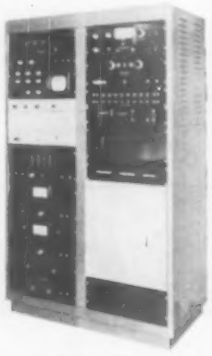

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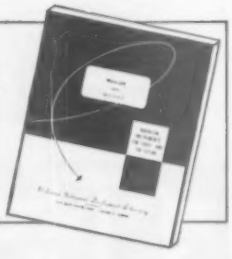

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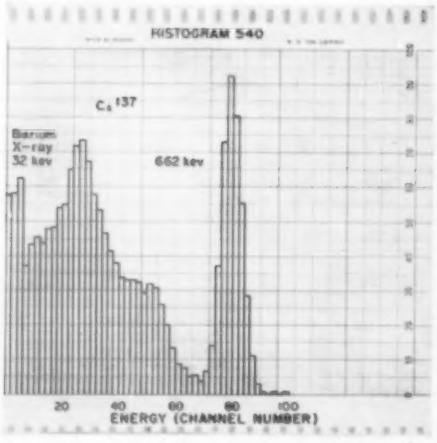


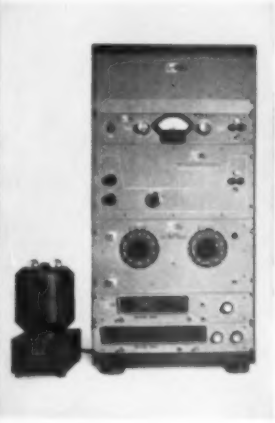

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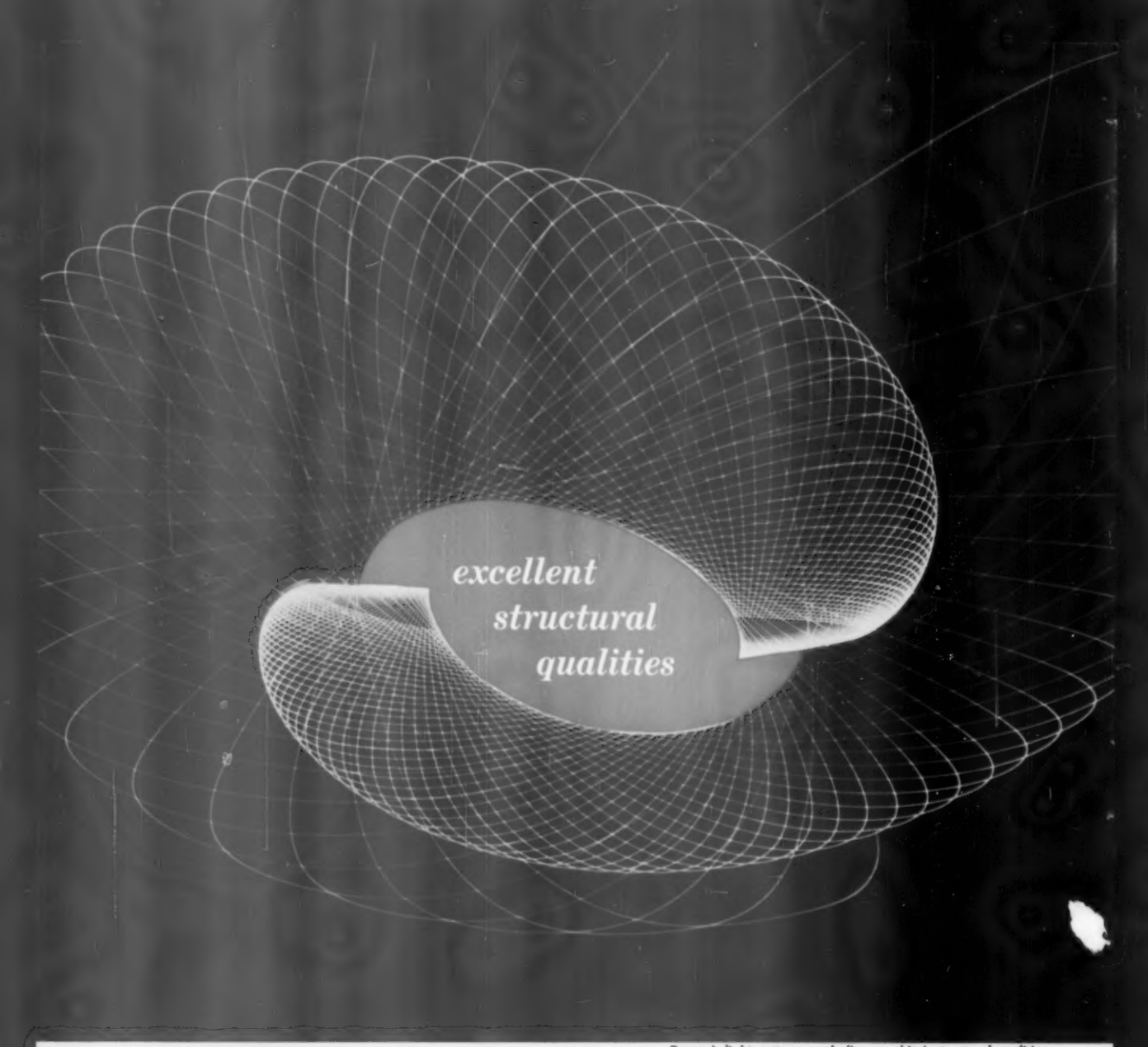


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